STUDIES ON PARBOILING OF RICE

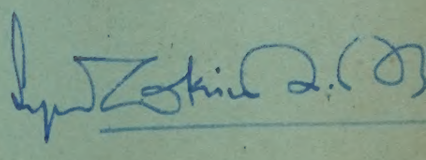
A Thesis Submitted for The Degree of
Doctor of Philosophy
of
THE UNIVERSITY OF MYSORE

by
SYED ZAKIUDDIN ALI, M.Sc.

CENTRAL FOOD TECHNOLOGICAL RESEARCH INSTITUTE
MYSORE - 570 013
JANUARY 1979

With
Deepest regards
To
My guide
Dr. K. R. Bhattacharya

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DECLARATION

The work incorporated in this thesis was carried out by me in the Discipline of Rice & Pulse Technology, Central Food Technological Research Institute, Mysore, under the guidance of Dr. K.R. Bhattacharya, M.Sc., D.Sc., Scientist.

I declare that the work embodied in this thesis has not been submitted previously for the award of any degree, diploma or any other similar title.

Mysore
Jan. 15, 1979

Syed Zakiuddin Ali

CERTIFICATE

Certified that this thesis entitled "Studies on Parboiling of Rice" is the result of research work carried out by Shri Syed Zakiuddin Ali, under my guidance, at the Discipline of Rice & Pulse Technology, Central Food Technological Research Institute, Mysore.

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Syed Zakiuddin Ali

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Chapter I

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1.0. INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important cereal crops of the world. It is the staple food for more than half the human race (FAO 1954, MATZ & BEACHELL 1969). Over 90% of world's rice is grown and consumed in south, east and south-east Asia (MASSEY-FERGUSON 1967, MATZ & BEACHELL 1969). During 1976 the world production of paddy (ranking only next to wheat) was 345 mn tonnes (FAO 1977).

India grows about one-fifth of world's rice and is the second largest producer of the crop. During 1976 its production marked 70.5 mn tonnes grown over 38.6 mn ha (yield 1.8 tonnes/ha) (FAO 1977). It is the most important crop of India, accounting for about 25% of the cropped area, 40% of the food production and nearly 20% of the GNP (BHATTACHARYA 1978).

Unlike other cereals, rice is mostly cooked as whole milled grains for consumption. Generally, the paddy is either milled as such which yields 'white rice' or 'raw rice', or is given a pre-milling cooking treatment called 'parboiling' which after milling gives 'parboiled rice'.

Parboiling is a very ancient process which originated in India and is still followed widely in the country (GHOSE et al 1960). Apart from India and other countries of the Indian subcontinent (Bangladesh, Pakistan, Nepal, Sri Lanka), parboiled rice is also consumed in parts of many other countries

of Asia and Africa, particularly among descendants of Indian origin (TATA 1964, BORASIO & GARIBOLDI 1965).

It is estimated that about one-fifth of the world's rice (TATA 1964, GARIBOLDI 1974) and more than half of the Indian production goes through parboiling process. In India it is the staple food of people in the coastal States of eastern and southern parts of the country (GHOSE et al 1960, TATA 1962, CFTRI 1965).

The subject of parboiling has been widely reviewed (KIK 1945b, 1946 , 1955, KIK & WILLIAMS 1945, NARAYANASWAMI 1956, GRIST 1959, GHOSE et al 1960, TATA 1962, 1964, BORASIO & GARIBOLDI 1965, KESTER & MATZ 1970, GARIBOLDI 1972, 1974, ALI & OJHA 1976a).

2.0. PRINCIPLES OF PARBOILING

Parboiling literally means partial boiling. In practice, it means boiling (i.e. cooking) of the rice within the husk (so as to retain its size and shape) after which it is dried back. In other words, parboiling (or hydrothermal treatment, as some recent workers call it) is nothing but rice precooked in paddy form (BHATTACHARYA 1978).

Cooking implies hydration and gelatinization of starch. So the two components of the process are (i) water and (ii) heat.

When starch is put in water at room temperature, it hydrates slowly, ultimately coming to an equilibrium at around

30% moisture (wet basis, w.b.). No appreciable change occurs when this slurry is heated, until at a particular temperature the granules suddenly start to swell and hydrate very rapidly. At the same time, the slurry becomes viscous and also more translucent. This phenomenon is called gelatinization of the starch and the range of temperature over which it occurs is called the gelatinization temperature range. This range usually lies between 50° and 80°C.

Parboiling of paddy is basically the same process as above. The starchy kernel is first hydrated by immersion in water and then gelatinized or cooked by heat. Since the size and shape of the grain are to be retained, the excess water after hydration is removed so that the swelling consequent upon gelatinization is not excessive.

Water and heat can be applied simultaneously (e.g. in home-scale methods). But in this case the process is not very efficient as either it leads to over-cooking (bursting of the grains and deformity of the final product), or under-cooking (where the grains are not fully hydrated and the centre remains uncooked, i.e. the grains have a white central core or 'white belly') (BHATTACHARYA & SUBBA RAO 1966a). More conveniently, the water and heat are applied separately -- as in commercial methods. First, paddy is hydrated by soaking in water (without gelatinizing) to about 30% moisture, the excess water is drained off, and the soaked paddy is heated (usually by steam) to gelatinize the starch. Soaking and steaming, therefore, are the two essential steps in the parboiling of paddy.

2.1. Soaking

The rate and extent of hydration of paddy during soaking depend on the temperature and time of soaking as well as on the variety of paddy (gelatinization temperature of the particular starch). Although a number of earlier workers briefly touched on these aspects during their technological and nutritional studies (CHARLTON 1923, SUBRAHMANYAN et al 1938, KIK & WILLIAMS 1945, JONES et al 1946, SANJIVA RAO 1948 and SUBRAHMANYAN et al 1955), systematic work on the hydration characteristics of paddy was carried out only recently.

MECHAM et al (1961) observed that the absorption of water by paddy increased with the increase in the temperature of soaking. There existed a moisture gradient within the grain, particularly at higher temperatures, because of which it was felt desirable to hold or temper the soaked paddy for some time (to equalize the moisture) before steaming.

BHATTACHARYA & SUBBA RAO (1966a), while generally confirming the above findings, observed that there were two distinct patterns of water absorption depending on the actual temperature used. Upto 60°C, the paddy absorbed water at a relatively slow rate and reached an equilibrium level around 30% moisture (w.b.). But at 75°C and above, the rate, after an initial phase, increased sharply and progressively. Soaking at 70°C represented a transition point between these two patterns (Fig. 1). The hydration was thus clearly related to the gelatinization of the starch, the rate of absorption of water increasing sharply once

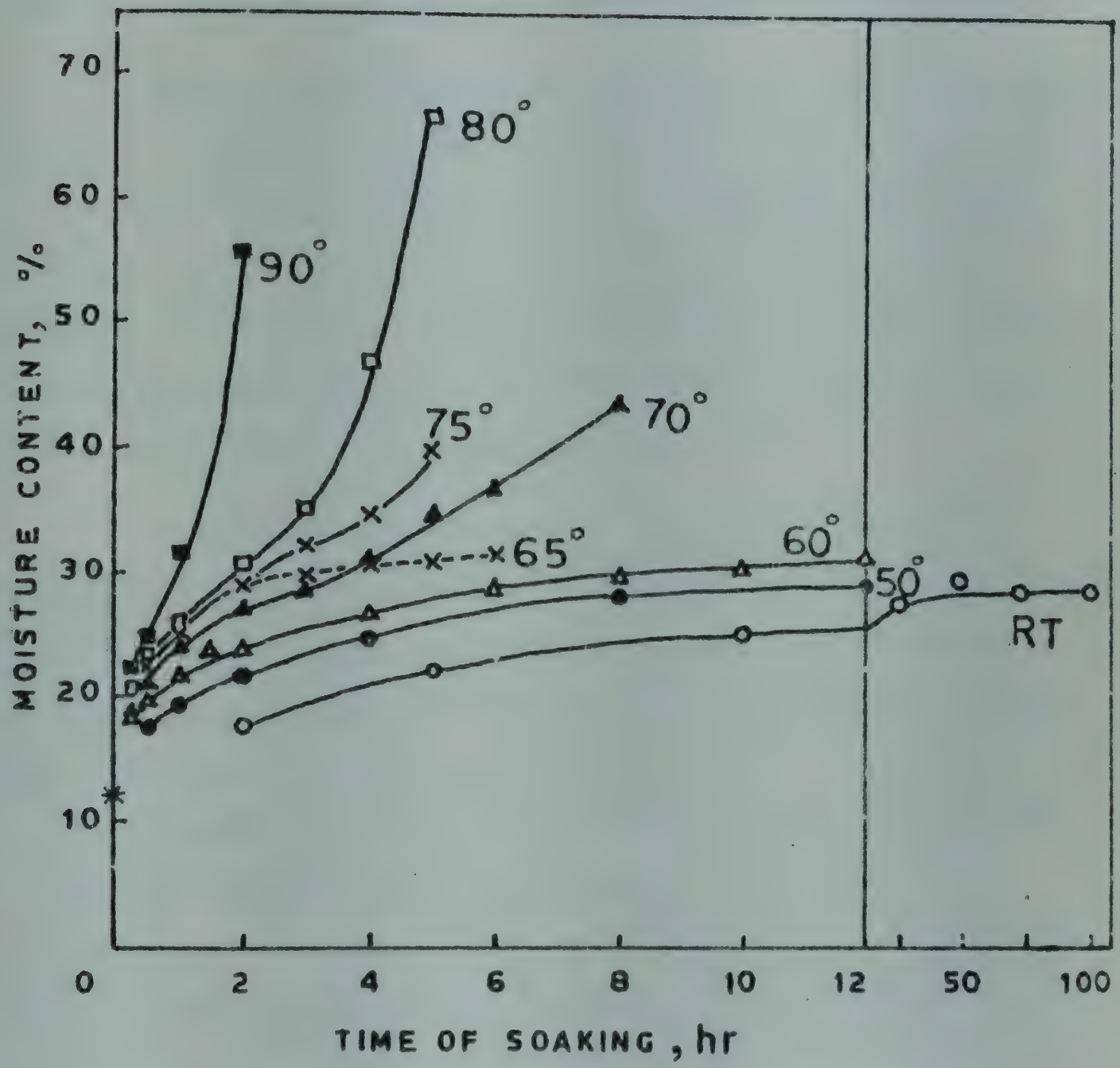


Fig. 1. Hydration of paddy at different temperatures.

RT, room temperature (23-27°C); * Moisture of original paddy (11.5%)

(BHATTACHARYA & SUBBA RAO 1966a)

the gelatinization of the grain set in. Essentially similar findings have been reported recently by ALI & OJHA (1976b).

The optimal temperature of soaking was thus around 70°C. The moisture gradient in the grain at this or lower temperatures was not sufficiently high to warrant a tempering step before steaming. Mere soaking of paddy at 80°C (without further steaming -- resembling the home-scale methods of parboiling) yielded partially parboiled rice (with white belly) which in many ways behaved like fully parboiled rice.

BANDOPADHYAY & GHOSE (1965) studied the hydration kinetics of paddy and developed a mathematical diffusion equation for the process. The activation energy calculated from this relationship could be used for predicting the optimal soaking time of a variety (BANDYOPADHYAY & ROY 1975). The onset of rapid hydration at high temperatures has been also correlated with rapid increase in the activation energy, grain volume (swelling) and bursting of the husk (BANDYOPADHYAY & ROY 1975, 1976 1977, ALI & OJHA 1976c), showing that all these phenomena were closely related to the gelatinization temperature.

2.2. Steaming

The purpose of steaming the soaked paddy is to gelatinize the starch. About 2 minutes' open steaming is enough to accomplish the gelatinization *per se* (BHATTACHARYA & SUBBA RAO 1966a). However, in practice, a longer period of steaming

either at atmospheric pressure (in Orient) or under raised pressure (in patented Western processes) is used.

2.3. Effect of Processing Conditions on Rice Quality

Conditions of soaking and steaming (temperature, pressure, duration) determine the cooking quality and colour of the resultant parboiled rice. The greater the severity of heat treatment during the above two steps, the lower is the water uptake of the resultant rice and the darker its colour. Soaking at high temperatures had a greater effect on the colour, while steaming affected the cooking quality to a greater extent (BHATTACHARYA & SUBBA RAO 1966b). Longer time of steaming has also been observed to enable the grain to better withstand adverse drying conditions without damage to its milling quality (BHATTACHARYA & SUBBA RAO 1966a).

3.0. METHODS OF PARBOILING AND DRYING OF PARBOILED PADDY

Parboiling has been carried out by small, home-scale methods for centuries. Large-scale methods were adopted for commerce from the early part of the present century. The need to eliminate the pronounced defects of these processes inspired the development of a few improved processes in India during the last few decades. Several highly mechanized, patented processes have been adopted in the West after the nutritional and technological value of parboiling became widely known.

3.1. Primitive Home-Scale Methods

There exist a number of home-scale methods which have been followed and are still practised in many rural parts of India and Africa (NARAYANASWAMI 1956, GHOSE et al 1960).

The processes consist of putting paddy in water in a container (metallic or earthenware) and heating it to near or actual boiling point. Heating is generally continued until a few grains burst. It is then either drained immediately and dried or allowed to cool and then drained, or in some cases, heated for a second time for a brief period after overnight standing. In some areas, the paddy is soaked in warm water and then roasted with sand in iron pans over a fire before it is dried. The product in this case is called 'sela' rice.

3.2. Traditional Commercial Processes

The two commonest large-scale methods being practised in India and elsewhere are the so-called (i) single-boiling and (ii) double-boiling methods (GHOSE et al 1960, ALI & OJHA 1976a).

In the 'single-boiling' process, paddy is soaked in big rectangular cement tanks in water at ambient temperature for 2 - 3 days and then transferred to cylindrical steel kettles for steaming in small batches at atmospheric pressure. The parboiled paddy is then dried in sun in big paved yards before milling.

In the 'double-boiling' or 'do-bhamp' process, the raw paddy is first steamed in the steaming kettles before soaking.

The hot paddy raises the temperature of the soak water to about 45°C or so, which hastens the imbibition of water and reduces the soaking time to 24-36 hr. Thereafter, the soaked paddy is again steamed as in the single-boiling method. In some cases, the paddy is heaped and covered for 6-8 hr after the first steaming. This variation is called the 'champ' process and yields slightly dark-coloured rice.

Other methods are also used to a limited extent. In the 'chatti process', followed in Sind of Pakistan, paddy is soaked in a battery of earthenware pots over a smouldering mixture of paddy husk and huller bran for 6-12 hr and then toasted over shallow iron pans. Soaking and steaming in false-bottom rectangular tanks is also prevalent in some parts of Sri Lanka and in Kerala.

3.3. Defects in the Traditional Commercial Methods, Causes and Remedies

Parboiled rice produced by the above large-scale processes suffers from the serious drawback that it possesses a characteristic disagreeable odour and off-flavour (CHARLTON 1923, SANJIVA RAO 1948a, 1948b, DESIKACHAR et al 1955). The process is also rather unhygienic and may cause development of mycotoxins in the rice (ALI & OJHA 1976a).

The off-flavour has been traced to fermentation which sets in during the prolonged steeping step, particularly at ambient temperatures. A few species of bacteria and yeast which

are primarily responsible for this fermentation have been identified (DESIKACHAR et al 1955).

Efforts were therefore made to control or eliminate the fermentation. Frequent changes of soak water can minimize but not eliminate the odour completely (CHARLTON 1923, DESIKACHAR et al 1957).

It has been shown that the fermentation could be checked either by suitable chemicals or by raising the temperature of soak water sufficiently. Chemicals like chlorine, calcium sulphate (with dilute sulphuric acid) and dilute acetic acid have been suggested. But this principle has not been applied in practice due to the inherent hazards. However, recently, use of potassium chromate has been claimed by SUBRAHMANYAN (1972) to completely eliminate the foul smell; in addition, it has also been claimed to give a higher yield of milled rice than the conventional methods.

Soaking at high temperatures, on the other hand, has been found to be more feasible. This was first suggested by CHARLTON in 1923 but not much attention was paid towards this, until after about three decades when detailed studies were carried out by many other workers (SANJIVA RAO 1948a, 1948b, BARRON 1949, INTERNATIONAL RICE COMMISSION 1949, BRITISH GUIANA REPORT 1950, SANJIVA RAO & GUHA 1952, DESIKACHAR et al 1957). Hot water soaking has the additional advantage of reducing the period of soaking to 2-6 hr.

Detailed studies and developmental work was subsequently taken up at two centres in India, viz. the Central Food Technological Research Institute (CFTRI) at Mysore and Jadavpur University, Calcutta, whereby two modern methods were developed. Processes developed in the Western countries too involve the same principle of hot-water soaking, but in addition incorporate highly mechanized and sophisticated technology for the various operations.

3.4. Modern Processes

In the CFTRI process (GHOSE et al 1960, TATA 1962, 1964, SARDA 1965) the paddy is charged into hot water (about 85°C) in big cylindrical overhead steel tanks. The temperature of the mixture drops to about 70-75°C. Soaking is continued for 3-3.5 hr and the soak-water is recirculated once or twice inside the tanks to effect uniformity of temperature throughout the tank. Water is then drained off and open steam (originally at 50-100 psig) is passed through perforated steam pipe arrangements in the tanks, till it emerges from the top and bottom. The steamed paddy is dried in sun or in mechanical dryers. Although a batch process, it could be made semi-continuous by suitable staggering of the operations of a number of tanks.

The process developed by Jadavpur University is continuous (MAZUMDER et al 1960a, 1960b, BORASIO & GARIBOLDI 1965). It consists of a long, trough-shaped, jacketed soaker-steamer, through which paddy is slowly propelled by a paddle shaft. At the end of the soaker, the paddy is automatically

scooped out and put into the steaming section, where it is steamed for a few minutes. The paddy is cooled in a tower before it is finally dried in a rotary drier. This process has not yet been adopted commercially.

A modified CFTRI method using brine solution in one operation was recently developed at the Paddy Processing Research Centre (PPRC), Tiruvarur, Tamil Nadu (SHIVANNA 1971, VASAN et al 1973). The hot-soaked paddy (65°C, 4.5 hr) is given a further 10-20 min soaking in 15% brine solution, which brings down the moisture content from 28-30% to 23-24%. After steaming, paddy takes less time for drying, thus bringing down the drying cost. In a further modification, the soaked paddy is just washed in brine and then steamed.

The PPRC has also suggested a pressure-parboiling method in which both soaking and steaming steps are carried out with high-pressure steam (SHIVANNA 1971). It is claimed that the processing time is further reduced to about 1-1.5 hr.

A few other methods also have been developed but are yet to find commercial use (KUPPUSWAMY 1972, KISAN KRISHI YANTRA UDYOG 1972).

Modern processes of parboiling developed in the Western countries involve a great deal of mechanization. Patented processes are available in USA, Italy and France. Avorio and Cristallo processes of Italy, Conversion and Malek

processes of USA and Fernandez process in Surinam (South America) are widely known (BORASIO & GARIBOLDI 1965, GARIBOLDI 1972, ALI & OJHA 1976a), but some others on which numerous patents exist (e.g. DURRANI 1950, 1956, JONES & BREWER 1950, LANDON et al 1951) have not become commercially popular yet.

3.5. Drying of Parboiled Paddy

After steaming, parboiled paddy usually contains around 35% moisture (w.b.) or more, which must be brought down to 14% or less before it is stored or milled. Traditionally, sun drying has been adopted, which is still widely followed in Asian and African countries. Of late, mechanical drying has also come into practice, particularly in the West.

It is now well recognised that milling quality of parboiled rice is strongly dependent on the conditions of its drying. While proper drying can practically avoid breakage of rice entirely, improper drying could lead to even 100% breakage. Drying thus plays the most crucial role in the technology and economics of parboiling (BHATTACHARYA & INDUDHARA SWAMY 1967).

Systematic studies on the occurrence of breakage during drying and factors affecting it have been conducted by CRAUFURD (1960, 1962, 1963, 1964), SLUYTERS (1963, 1965) and BHATTACHARYA & INDUDHARA SWAMY (1967). These studies have shown that slow drying (e.g. in shade) gives very little or negligible breakage, whereas fast drying (e.g. hot-air or sun)

can potentially lead to considerable breakage during milling. During drying, moisture from the central portions of the grain has to travel to surface before it can evaporate. If the rate of evaporation is faster than that of moisture diffusion from the centre to the periphery (as in the case of fast drying), there develops a moisture gradient within the grain, and when it becomes excessive the stress is released by the formation of cracks in the grain.

It has been found that the critical moisture content, at which cracks develop on continued fast drying of parboiled paddy, is around 16%. A rest period (tempering) for a few hours before this stage allows the equilibration of moisture and eliminates the crucial stress and thereby prevents the formation of cracks (BHATTACHARYA & INDUDHARA SWAMY 1967).

The above principles were subsequently applied successfully to the commercial-scale drying of parboiled paddy both by sun (BHATTACHARYA & ALI 1970) and by mechanical dryers (BHATTACHARYA et al 1971).

Recently, RAMA RAO & BONDE (1977), working with a miniature model of LSU type dryer, have reported similar results.

4.0. BENEFICIAL EFFECTS OF PARBOILING

Parboiling confers some outstanding technological and nutritional benefits on rice. This aspect has been reviewed by several authors (KIK & WILLIAMS 1945, JONES et al 1946,

BORASIO & GARIBOLDI 1965, DESIKACHAR et al 1967, HOUSTON & KOHLER 1970, ALI & OJHA 1976a).

4.1. Improvement in the Milling Quality of Rice

During the process of parboiling, the husk opens slightly due to swelling of the kernel. This makes the dehusking operation easier, thereby increasing the shelling capacity of the mill.

Secondly, a marked increase in the head rice as well as total rice outturn from paddy as a result of parboiling is well recognized. The decrease in breakage is often dramatic. As a matter of fact, this improvement in the milling quality sometimes more than offsets the cost of processing, and often parboiled rice is sold at a cheaper rate than raw rice. This improved milling quality arises from healing of kernel defects (cracks, chalkiness) as a result of realignment and cementing of the grain constituents upon cooking of the starch during parboiling (BHATTACHARYA 1969). Of course, as mentioned before, this benefit depends upon proper drying of the parboiled paddy itself, which otherwise may again crack severly and give very poor yield.

Contrary to the above advantages, parboiling also causes some minor disadvantages during milling. Firstly, due to hardening of the grains, parboiled rice requires a greater force or longer time to mill (SREENIVASAN 1936, 1951, RAGHAVENDRA RAO et al 1967). Secondly, polishing of parboiled brown rice leads to some problem of rice stickiness and clogging of the mill

screen. The resultant rice also has a rather unattractive appearance (RAGHAVENDRA RAO et al 1967). This problem is usually overcome by addition of a little husk during polishing, or by milling the paddy directly in an Engelberg huller. This property is related to the greater surface oil content of milled parboiled rice (HALIM & BHATTACHARYA 1978), discussed later.

4.2. Improvement in the Nutritive Value of Rice

One of the outstanding advantages of parboiling is the improvement it brings about in the nutritive value of rice. Most of the vitamins and minerals in the rice grain are located in its outer layers (aleurone and germ) and are largely lost during milling. Parboiling increases the nutritive value of the resultant milled rice by reducing this loss. This subject attracted considerable attention from the time of several classical studies on beri beri and its relation to thiamine deficiency, and has been extensively reviewed (AYKROYD et al 1940, KIK 1945a, KIK & WILLIAMS 1945, HOUSTON & KOHLER 1970 etc). Parboiling actually slightly lowers the total B_1 content of the original grain, but whatever remains is much better protected against milling loss (SUBBA RAO & BHATTACHARYA 1966). Other vitamins (riboflavin, niacin), minerals (Ca, P, Fe) and even protein are also similarly protected.

The other nutritionally beneficial effect of parboiling is that it reduces the loss of nutrients during washing and cooking of the rice. KIK (1955) has reported that the biological

value, protein efficiency ratio and digestibility coefficient of rice protein are markedly improved upon parboiling.

4.3. Storage of Parboiled Rice

The storage behaviour of rice is, on balance, improved by parboiling. Hydrolytic rancidity due to splitting of fat to free fatty acids is completely checked as a result of inactivation of rice lipase. However, parboiled rice is more prone to oxidative rancidity leading to deterioration of aroma and flavour (KIK & WILLIAMS 1945, HOUSTON et al 1954). Destruction of some native antioxidants by parboiling treatment is postulated to be the cause for this (SOWBHAGYA & BHATTACHARYA 1976).

Parboiled rice has also been claimed to be more resistant to infestation by insects and moulds. It is considered that the greater hardness and the smooth surface of the gelatinized grain makes it harder for the insects to attack it.

5.0. CHANGES DURING PARBOILING AND QUALITY OF PARBOILED RICE

Parboiling of paddy brings about profound changes in the properties of the rice. The appearance, physical, physicochemical, nutritional, milling and cooking qualities of rice are all altered to a greater or lesser extent. These changes again are dependent on the severity of heat treatment which the paddy receives during the whole process. This aspect of parboiling -- other than that related to nutritional improvement -- did not

receive much attention in the past, but a good deal of information has become available in recent times. The available information is reviewed below.

5.1. Morphological and Physical Changes

5.1.1. Grain dimensions: A slight decrease in length and increase in breadth of the milled parboiled grains, as compared to raw rice, has been observed by many workers (SREENIVASAN 1936, KHUDA et al 1962, KURIEN et al 1964). Rounding off of the germ tip of milled parboiled rice (KURIEN et al 1964) and the absence of the cavity at the germ tip (NICHOLLS 1947) due to absorption and incorporation of a part of the germ (BORASIO & GARIBOLDI 1965) are described as the reasons for the decrease in length and consequent alteration of length to breadth ratio (and hence the shape of grain). Contrary to these observations, DIMOPOULOS & MULLER (1972) report an increase in grain length, which appears rather doubtful.

5.1.2. Retention of germ and scutellum: NICHOLLS (1947) observed that the site of germ got flattened in milled parboiled rice as though only a part of the germ has been lost during milling and the scutellum remained adherent to the endosperm. HINTON (1948) also observed a similar effect and attributed it largely to the gelatinization of endosperm immediately beneath the germ, which acts as a cementing layer so that the germ is not readily knocked out during milling. He also noted that more than 90% of the parboiled milled grains retained some germ,

although the average germ content of each grain was very low (0.09%). On the other hand, only about 6% of the grains in raw milled rice retained some germ, but the germ content of such grains was relatively high (1.7%).

5.1.3. Translucence: Rice grains become more translucent on parboiling; they also lose their opacity, caused by any chalky areas, consequent upon gelatinization of the starch (JONES & TAYLOR 1935, BHATTACHARYA 1969, RAGHAVENDRA RAO & JULIANO 1970). Even the cracks present in the original kernel are completely healed by parboiling (BHATTACHARYA 1969). However if the time of soaking is insufficient, an ungelatinized white centre (white belly) is observed in the grain (SUBRAHMANYAN et al 1955, MECHAM et al 1961, BHATTACHARYA & SUBBA RAO 1966a).

5.1.4. Colour of parboiled rice: After parboiling, the finished rice acquires a colour varying from light yellow to medium amber. This discolouration is chiefly due to nonenzymatic browning of the Maillard type (HOUSTON et al 1956), as it is largely inhibited by bisulphite (HOUSTON et al 1956, MECHAM et al 1961, JAYANARAYANAN 1964). But other factors also seem to be involved. A part of the bran might be embedded in the endosperm during parboiling (SUBBA RAO & BHATTACHARYA 1966b), which would add to the colour of the rice, more so because this layer is itself darkened by Maillard reaction, being rich in free sugars and amino acids (WINTON & WINTON 1932). The husk pigment may also contribute by diffusing into the endosperm

(SUBRAHMANYAN et al 1938) or by being absorbed on splitting of the grain during soaking (BHATTACHARYA & SUBBA RAO 1966b).

Dextrinization of starch during parboiling has also been postulated to be responsible for the darkening of the grains (TATA 1964). But this seems doubtful.

The processing conditions during parboiling have an important bearing on the colour of the parboiled rice. Measurement of the colour of parboiled rice, in fact, has been employed as an indirect index of the severity of parboiling (JOHNSON 1965, STERMER 1968).

SUBRAHMANYAN et al (1938) had observed that short periods of soaking and steaming gave less colour in the finished rice. ROBERTS et al (1954) studied the effect of temperature of steaming (70°-150°C, 4 min each) on the colour. They observed that the intensity of discolouration increased rapidly upto 100°C then apparently tapered off, and then increased again when the temperature exceeded 123°C or when the soaking time and temperature were excessive. They postulated that reducing sugars from the bran layers and embryo get absorbed into the endosperm and react with free amino acids to produce browning while steaming. MECHAM et al (1961) reported that overcooking during steaming step resulted in darkening of grains. Steaming time as well as its pressure affected the colour of rice. Thus, samples cooked for 8 min at atmospheric pressure were lighter in colour than those cooked for 5 min at 20 psig, which in turn were slightly lighter than those cooked for 8 min at 20 psig.

A more comprehensive investigation on the effect of processing conditions on the colour of parboiled rice was carried out by BHATTACHARYA & SUBBA RAO (1966b). They observed that increasing temperatures of soaking upto 60°C had little influence on the colour of the rice, but soaking at 70°C and above produced progressively increasing effect (Fig. 2). The time and pressure of steaming also affected the colour (Table 1), but this effect was less as compared to that of soaking temperature.

T a b l e 1

Effect of steaming time on the colour of parboiled rice

Condition of parboiling			Colour difference ΔE
Soaking		Steaming time (min)	
Temp. (°C)	Time (hr)		
70°	2.5	2	8.8
		5	9.2
		10	10.0
		20	12.1
		40	11.4
		60	12.1

BHATTACHARYA & SUBBA RAO 1966a

The combined severity of heat treatment during soaking and steaming, therefore, determined the colour of the finished rice. The authors suggested the use of relatively low

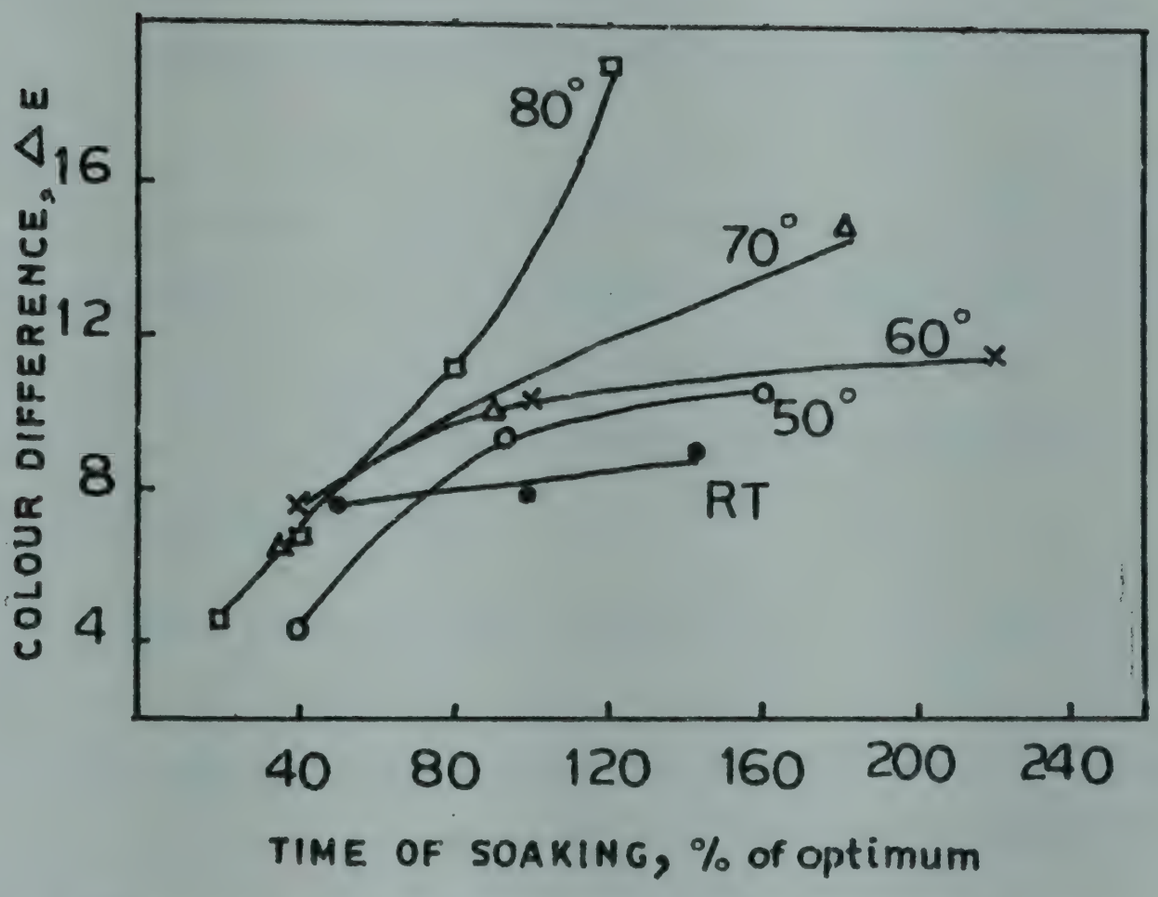


Fig. 2. Effect of temperature and time of soaking on colour of parboiled rice.

(All samples steamed for 10 min at 0 psig.)

(BHATTACHARYA & SUBBA RAO 1966b)

temperatures (below 70°C) for soaking, and for the minimum time, as well as the minimum time of steaming if parboiled rice of lighter colour was desired. Reverse conditions would be needed for highly discoloured rice.

KIREEV & MELNIKOV (1974) also reported similar observations.

An effect of pH of the soak water was demonstrated by JAYANARAYANAN (1964). The colour of parboiled rice increased on either side of pH 4-5. However, his data needs to be revaluated as the colour was measured by him apparently on brown rice without any milling.

More recently ALARY et al (1977) have observed that, conditions of processing being constant, the colour (yellowness) of milled parboiled rice increased with increasing amylose content of rice from 22% to 27% and decreased slightly thereafter upto 29%.

5.1.5. Physical properties: Very interesting observations on the changes in physical properties of rice due to parboiling have been reported by BHATTACHARYA et al (1972a). Parboiled brown rice packed slightly better (i.e. had higher bulk density and less porosity) and flowed more freely (i.e. showed less angle of repose or coefficient of friction) than raw brown rice. However, the pattern changed on milling. In both rice, packing and flow properties first deteriorated and then

improved with progressive milling. But the initial deterioration was only slight in raw rice while it was severe in parboiled rice. As a result, partially milled parboiled rice packed and flowed very poorly (very low bulk density and very high coefficient of friction).

These results were in agreement with the well-known stickiness of partially milled parboiled rice. All these properties are related to the outward movement of fat in the rice grain upon parboiling (discussed in detail later) resulting in a higher content of surface fat in partially milled parboiled rice compared to in raw rice.

5.2. Histology of Parboiled Rice

KHUDA et al (1962) described the cellular structure of the rice grain. In sections of raw rice, the starchy endosperm was bounded by the seed coat, and free starch granules were visible within the cells (sometimes in clusters). The starchy cells were opaque to transmitted light. On parboiling, the granules lost their opacity and became partially transparent. The authors also studied the response of the sections to iodine staining. They noted considerable varietal differences both in raw and in parboiled rice. But the starchy endosperm of raw rice was mostly stained deep blue to violet (rarely pink), which changed to light violet or pink (rarely blue) in the parboiled sections. The authors inferred that some change in

the starch constituents had occurred (possibly dextrinization or a shift in the ratio of amylose to amylopectin).

Later RAGHAVENDRA RAO & JULIANO (1970) demonstrated that the orderly polyhydral structure of the compound starch granules changed to a coherent mass after parboiling. The completely translucent parboiled grains showed complete gelatinization of the starch granules throughout the endosperm, as seen by phase-contrast microscopy in sections after suitable staining. This was also confirmed by complete loss of birefringence in parboiled rice powder. Further, the distinct protein bodies as seen in the raw rice grain (del ROSARIO et al 1968) were no longer distinct in sections of parboiled rice.

Histological studies on the changes in the state of protein and fat were reported by DE & RAHMAN (1965) and MAHADEVAPPA & DESIKACHAR (1968a). The former authors noted that, in raw rice sections, protein and fat were uniformly distributed in the aleurone layers and also as the structural constituent of starch cells. In sections from parboiled rice, staining due to protein almost disappeared from the starch cells of the endosperm region. They therefore concluded that protein tends to migrate outside but is held up in the aleurone layer. Fat also showed a diminished staining which they ascribed to its dissociation from the starch constituents and movement outwards.

MAHADEVAPPA & DESIKACHAR (1968a) provided more satisfactory experimental evidence on the fate of these constituents as a result of parboiling. They observed a damage to the cell walls in the parboiled samples. The oil, which occurred mostly in aleurone and in the germ as discrete oil globules, lost its globular structure and became converted into a band or a layer. Rupture of the oil globules was seen even after mere soaking of paddy at 80°C just as after soaking at low temperatures followed by steaming. In some samples, the bran layer also appeared to have got slightly detached from the aleurone layer. These findings provide basis for the explanation regarding the changes in the frictional properties of milled parboiled rice, discussed earlier, and for the higher content of fat in the bran extracted from parboiled rice (discussed later).

MAHADEVAPPA & DESIKACHAR (1968a) further observed that the thin-walled loose spongy cells which separate the scutellum and endosperm get compressed on parboiling by expansion of the endosperm cells below them. Contrary to the reports of DE & RAHMAN (1965), these authors found that most of the protein remained <u>in situ</u> during parboiling and did not migrate outwards. RAGHAVENDRA RAO & JULIANO (1970) also supported the above finding and explained that the poorer staining of protein as observed by DE & RAHMAN (1965) could be due to the masking of protein bodies by the gelatinized starch.

5.3. Physicochemical and Chemical Changes

5.3.1. Sugars: WILLIAMS & BEVENUE (1953) observed that milled parboiled rice contained more sugars than milled raw rice. They thought that this might be due to migration of sugars from the bran layers into the interior during parboiling - just as in the case of the B vitamins. Contrary to this, TARASOVA et al (1971) report a decrease in the reducing sugar content by hydrothermal treatment of rice. SCHROEDER (1965) did not observe any detectable change in reducing sugars after parboiling when the rice was free from any microbial infection. However, fungal infection caused the disappearance of the reducing sugar in raw rice, which appeared again, and to a greater extent, on parboiling. The implications of these observations are not clear.

5.3.2. Starch and its properties: Considerable changes in starch and its properties due to parboiling have been reported.

Parboiling was widely known to cause gelatinization of rice starch. But this aspect lacked experimental evidence until RAGHAVENDRA RAO & JULIANO (1970) demonstrated that the A-type X-ray diffraction pattern exhibited by starch from raw rice was lost after parboiling along with the loss of birefringence of the starch granules. Recently PRIESTLEY (1976b) also reported the loss of A pattern after parboiling and identified the changed pattern as V.

A slight decrease in the total starch content as a result of parboiling was reported by TARASOVA et al (1971) and KUZ'MINA & TORZHINSKAYA (1973). Partial dextrinization of the starch was reported earlier (KHUDA et al 1962, TATA 1964, BORASIO & GARIBOLDI 1965). Again, enzymic interconversion of amylose and amylopectin fractions of starch due to parboiling was postulated by DE et al (1966) when they noticed a lowering of the wavelength of maximum absorption of the starch-iodine colour complex in some rice variaties, and an increase in the blue-value itself in some other varieties without any shift in the wavelength. However, all these results and postulates need to be further confirmed.

Contradictory observations regarding a change in the molecular size and weight and the amylose content of starch have also been reported. RAGHAVENDRA RAO & JULIANO (1970) did not observe any appreciable decrease in the molecular size of starch, while KUZ'MINA & TORZHINSKAYA (1973) reported a definite decrease. SIMPSON (1951) found that parboiled rice averaged slightly higher in amylose content as compared to raw rice, but KUZ'MINA & TORZHINSKAYA (1973) reported a decrease. Morphological changes in the volume and shape of the starch granules have been observed by TARASOVA et al (1971). Some confusion therefore exists in this field indicating probably the complexities of the problem or the inadequacy of the tools employed.

Changes in the viscographic properties of rice flour due to parboiling have been studied by some workers. A rise in the 'gelatinization temperature', i.e. the temperature of initial rise in viscosity (from about 65-75° in raw rice to 80-85°C in parboiled rice); a decrease in the breakdown; and a drop in paste viscosity as a result of parboiling have been observed (FERREL & PENCE 1964, RAGHAVENDRA RAO & JULIANO 1970, KUZ'MINA & TORZHINSKAYA 1973, ARAI et al 1975, PRIESTLEY 1976a).

An increase in the warm-water-soluble starch content (the so-called starch-iodine blue value) of rice as a result of parboiling, increasing with the severity of heat treatment during processing, was reported by ROBERTS et al (1954). They proposed this difference as a test of parboiled rice. These results were confirmed by DIMOPOULOS & MULLER (1972).

PRIESTLEY (1976a) recently observed that parboiled rice gave a V-type X-ray diffraction curve. From the characteristic peaks of the curve be concluded that amylose on parboiling gets transformed to an insoluble helical complex.

PRIESTLEY (1976b, 1977) further reported that the 'apparent solubility' of rice kernel (i.e. its water dispersibility by sonic vibration) increased with the degree of heat treatment during parboiling, when the property was measured immediately after steaming of the paddy. However, when the parboiled rice was dried, milled and then recooked in excess

water, the 'apparent solubility' (Fig. 3) decreased with increasing severity of parboiling. This was attributed to the formation of the insoluble amylose complex mentioned earlier. Thus he suggested the measurement of 'apparent solubility' as a useful index for the degree of parboiling. The 'apparent solubility' was also correlated to the height of the characteristic peak of the X-ray diffraction curve of parboiled rice -- positively immediately after parboiling, and inversely on recooking of the dried and milled rice.

Parboiling has been reported to improve the digestibility of rice starch as evidenced by its increased susceptibility to *in vitro* enzymic digestion (MAZUMDER et al 1960c, KUZ'MINA & TORZHINSKAYA 1973).

5.3.3. Amino acids and proteins: SCHROEDER (1965) observed that there was a decrease in the total free amino acids content of rice as a result of parboiling. He identified 15 free amino acids in the rice extracts. However, infection of raw paddy with a fungal species caused the appearance of 7 more free amino acids. Parboiling of such infected rice produced a decrease in some amino acids and a corresponding increase in others.

SUBRAHMANYAN et al (1938) observed that parboiled brown rice contained 1-3% more nitrogen than the corresponding raw rice. They attributed this to the inward diffusion of

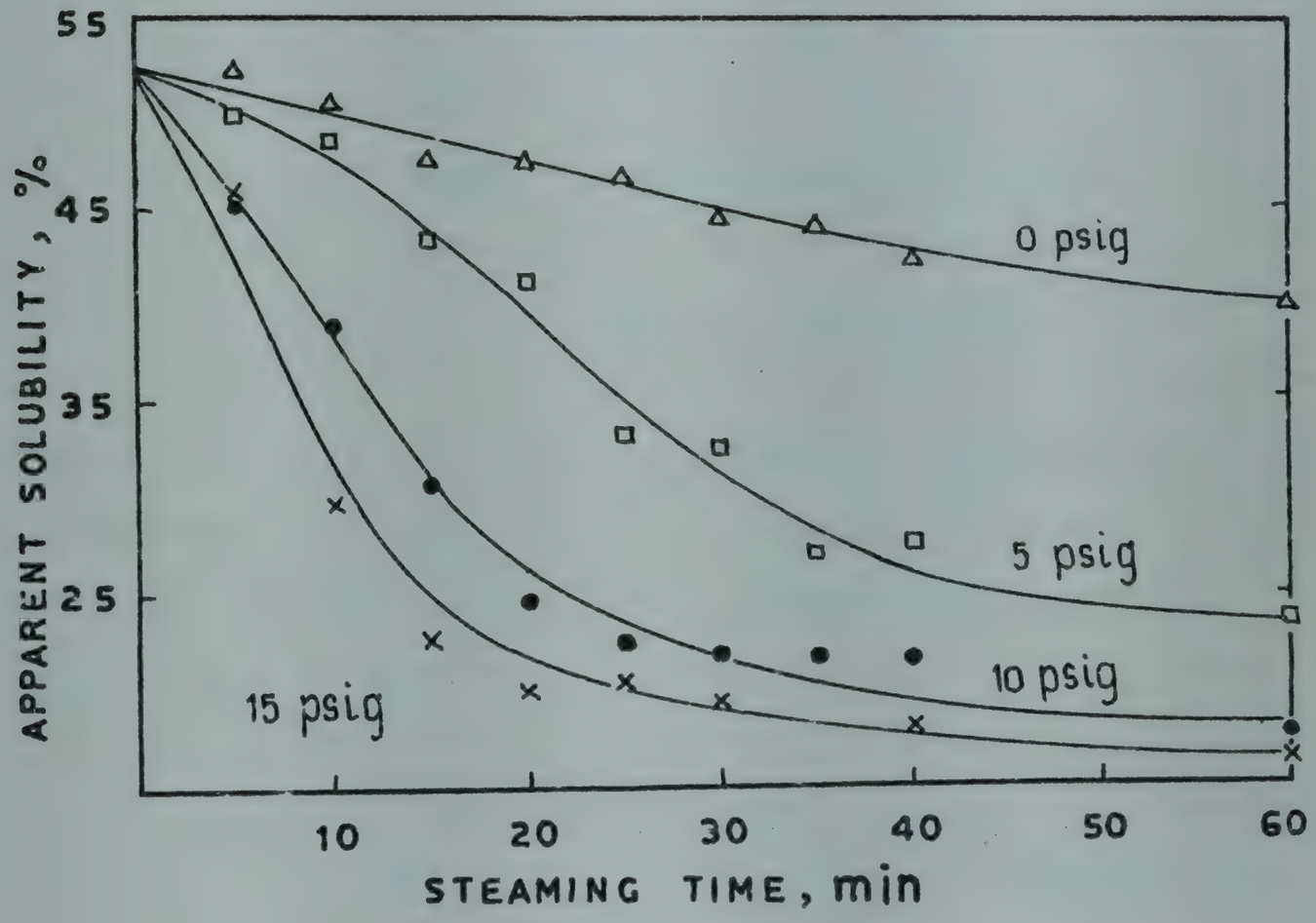


Fig. 3. Apparent solubility of cooked parboiled rice (Paddy parboiled by steaming under different pressure; milled parboiled rice cooked for 40 min)

(PRIESTLEY 1977)

nitrogenous constituents from the husk, in which they noted a corresponding decrease.

MITSUDA et al (1967) and del ROSARIO et al (1968) demonstrated that protein in rice grain exists in distinct fine spherical form or 'protein bodies', which occupy the space between the compound starch granules. These protein bodies were found to be no longer distinct after parboiling by RAGHAVENDRA RAO & JULIANO (1970), who further observed a decrease (about 45% on an average) in the extractibility of protein in serial extraction of different fractions, globulin being the one most affected. DIMOPOULOS & MULLER (1972) also observed that parboiling altered the protein solubility considerably in various solvents during serial extraction. The extractibility of protein in a 3% detergent (a straight chain, C 11, sodium alkyl benzene sulphonate) solution, among other solvents, decreased proportionately to the severity of steaming during parboiling (Table 2). Consequently they suggested the measurement of protein solubility in the detergent solution as a test to differentiate raw from parboiled rice and parboiled rices of different severity.

Denaturation of surface proteins has been reported by TARASOVA et al (1971) as a result of hydrothermal treatment of rice.

Improvement in the nutritional quality of rice protein in terms of digestibility coefficient, protein efficiency ratio,

Table 2

Effect of steaming pressure on protein extraction of parboiled rice *

Steaming pressure (psig)	% of total protein extracted by shaking in 3% detergent
Raw	73.4
5	31.4
10	25.9
15	20.1

DIMOPOULOS & MULLER 1972

* Paddy soaked at 64°C for 3.5 hr; steamed for 5 min each

biological value and net protein utilization was reported earlier by KIK (1954, 1955).

5.3.4. Fat: SREENIVASAN (1938) observed considerable movement of fat from germ into the bran in the rice grain after parboiling. This, however, has not been confirmed by any later worker. On the other hand, SUBRAHMANYAN et al (1938) observed, after parboiling under a variety of conditions, that milled parboiled rice contained less fat than milled raw rice. They therefore postulated that as water-soluble nutrients moved inwards in the grain during parboiling, fat moved outwards. Several workers later on observed that bran from milled parboiled rice contained more oil than that from raw rice at equal degrees of milling, which is in agreement with the above

postulation (KUMAR DAVID et al 1964, RAGHAVENDRA RAO et al 1965, CHAKRAVARTY & GHOSE 1966, VASAN et al 1971, PADUA & JULIANO 1974).

In further confirmation of the above, BHATTACHARYA et al (1972a) later on actually observed that the surface fat content of partially milled rice was higher in parboiled than in the raw grain. The surface fat content first increased and then decreased in the rice grain as it was milled, but the increase was much steeper after parboiling (Fig. 4). Actually this high surface fat was considered by these authors as responsible for the poor packing and flow properties ('stickiness') of intermediate-milled parboiled rice discussed earlier.

Histological studies of MAHADEVAPPA & DESIKACHAR (1968a), discussed earlier, describe very well the rupture of the discrete oil globules and their conversion into a band adjacent to bran layer. These findings corroborate as well as explain the other findings and properties mentioned above.

There is some doubt whether the conditions of parboiling influence this outward movement of oil. The oil content of bran was reported to increase further with increase in the temperature (CHAKRAVARTY & GHOSE 1966) and duration (VASAN et al 1971) of soaking as well as with increasing pressure of steaming (PADUA & JULIANO 1974). Contrary to these findings, SONDI (1976), in an experiment with carefully controlled degrees

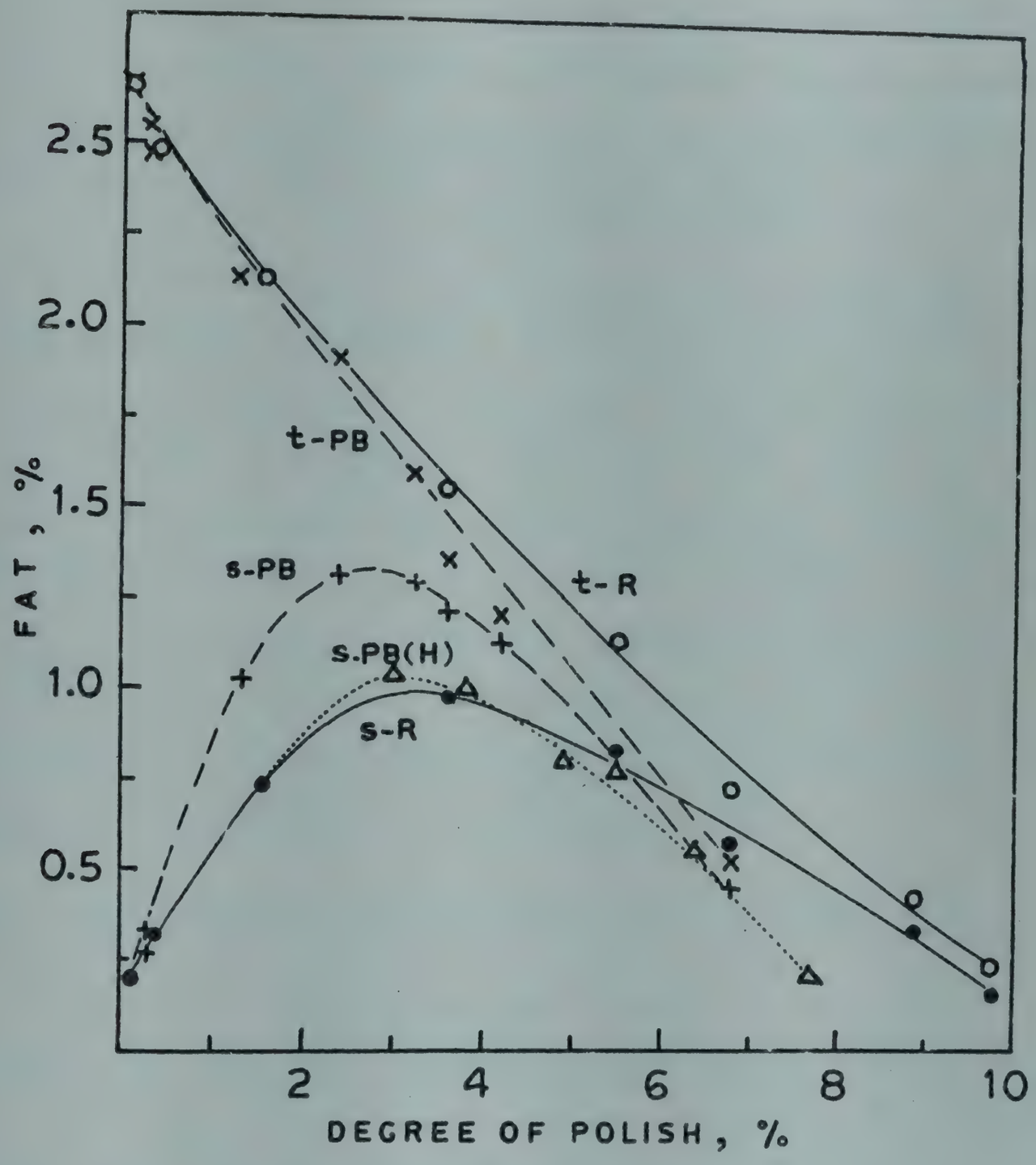


Fig. 4. Change in total (t) and surface (s) fat content of raw (R) and parboiled (PB) rice with progressive milling.

PB(H), parboiled brown rice milled with addition of husk.

(BHATTACHARYA et al 1972a)

of milling and after calculating the complete oil balance, observed that neither the temperature of soaking nor the duration of steaming during parboiling influenced the oil content of the bran when calculated for precise degrees of milling.

Although the fat of parboiled rice is practically free from hydrolytic deterioration due to inactivation of the enzyme lipase, it is more prone to oxidative rancidity (KIK & WILLIAMS 1945, HOUSTON et al 1954). Storage in light, higher temperatures of storage and lower moisture contents have been found to enhance and promote the fat autoxidation (SOWBHAGYA & BHATTACHARYA 1976). Destruction of naturally occurring antioxidants and the redistribution of the fat in the grain during parboiling are postulated to be the cause of enhanced lipid autoxidation in parboiled rice (SOWBHAGYA & BHATTACHARYA 1976).

5.4. Cooking Quality and Expanded Volume of Parboiled Rice

5.4.1. Cooking quality: Change in the cooking quality of rice after parboiling is well known. Parboiled rice takes a longer time to cook to a soft consistency, retains better shape after cooking, is fluffy and less cohesive, and loses less solids in the gruel during cooking (SUBRAHMANYAN et al 1938, JONES et al 1946, DONE 1949, KIK 1955, DESIKACHAR & SUBRAHMANYAN 1959 , 1961, KURIEN et al 1964, ARAI et al 1975, PRIESTLEY 1976a). Less damage or disintegration of the cell walls (DESIKACHAR & SUBRAHMANYAN 1959) and a decrease in the length to breadth ratio of the grain after cooking (MAHADEVAPPA & DESIKACHAR 1968b) have

been reported. KURIEN et al (1964) also noted that parboiled rice grains after cooking appear bigger and bolder than cooked raw rice. However, the swelling rates and expansion ratios at any given time during cooking were lower for parboiled than for raw rice and the parboiled rice took nearly double the time (30-40 min) of raw rice for cooking to an equivalent soft consistency. They also found that mere soaking of paddy in hot water (60°-65°C) reduced the swelling quality of the resulting milled rice; steaming the paddy after soaking further reduced the swelling ratio, the effect being proportional to the time of steaming.

BHATTACHARYA & SUBBA RAO (1966b) made a systematic study of the cooking quality of parboiled rice under a wider range of processing conditions. Soaking alone of paddy upto 60°C had little or no influence on the water uptake of the resulting rice during its subsequent cooking. Water-uptake of milled rice decreased when the paddy was merely soaked at 70°C, and the effect progressively increased with progressively higher temperatures of soaking. Similarly, increasing severity of steaming of soaked paddy progressively decreased the water uptake during cooking of the resultant rice.

Parboiled rice with 'white belly' (i.e. obtained from undersoaked paddy) had a higher water uptake. The maximum influence on cooking quality appeared to be exerted by steaming. Heaping of hot paddy after steaming for a long period (as in 'champ' process) gave an effect similar to that of prolonged

steaming. Iodine-blue value of the gruel (excess cooking water) and loss of solids in gruel also decreased simultaneously as the water uptake of milled rice decreased with the increasing severity of soaking and steaming of paddy.

Similar observations as above were later on made by other workers (DIMOPOULOS & MULLER 1972, ARAI et al 1975, PRIESTLEY 1976a, ALI & OJHA 1977).

A mention may also be made of the development of transverse cracks in rice grains when put in water. DESIKACHAR & SUBRAHMANYAN (1961) observed that when put in water, milled parboiled rice required a much longer time to develop these cracks than milled raw rice. BHATTACHARYA & SUBBA RAO (1966b) found that the rate and extent of cracking decreased with increasing heat treatment during parboiling. Thus, this property too followed the pattern of water uptake of the samples during cooking.

As parboiling imparts a high degree of stability towards cooking and heat processing, parboiled rice finds its use in the preparation of canned rice (JONES et al 1946, HOGAN 1967, KESTER & MATZ 1970, BURNS 1972). The canning quality of rice mainly depends on its variety (amylose content) and the severity of parboiling. DEMONT & BURNS (1968) and FEILLET & ALARY (1975) observed that severity of heat treatment during parboiling improved the texture and appearance of canned rice but not its colour, which darkened.

5.4.2. Expanded volume: Expanded rice is a product prepared from parboiled milled rice by heating it in oil or air at high temperatures for a few seconds. ROBERTS et al (1951) observed that the temperature of puffing medium, the moisture content of the parboiled milled rice and its variety, all affected the degree of expansion. ROBERTS et al (1954) later on studied the effect of processing conditions of paddy during parboiling on this property. They found that upto 100°C of steaming temperature of paddy (for 4 min each) during parboiling, there was not much increase in expanded volume of the parboiled rice over that of raw rice. Thereafter, it increased sharply, proportional to the severity of steaming, reaching a maximum expansion of about 5.6 volumes at steaming temperatures of 130°C and levelling off at this value. They also found a good correlation between the expanded volume and the iodine-blue value of parboiled rice.

ANTONIO & JULIANO (1973) observed that moisture content of paddy at the time of steaming (which the authors noted was dependent upon the amylose content of the variety under identical processing conditions) influenced the expanded volume of milled rice during puffing. It was therefore postulated that in addition to parboiling conditions, amylose content of the rice also (inversely) influences the puffed volume of the resulting milled parboiled rice as it alters the degree of parboiling due to differences in the moisture absorbed during the soaking period.

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Chapter II

THE PRESENT WORK

1.0. INTRODUCTION

A review of the literature on parboiling of rice, as presented in the previous Chapter, indicates that a good understanding exists regarding the nutritional and technological benefits of parboiled rice. Sufficient advancement has also taken place in the evolution of the process from its primitive state to a modern, sophisticated industrial process. The various processing factors, their optimum conditions for a satisfactory product, and their effects on rice quality have also been well explored.

However, a great lacuna seems to exist in understanding the nature of the product itself. What are the factors that make parboiled rice so different from raw rice and render it the properties it exhibits? It is well known that gelatinization of the starch takes place during parboiling. Certain other changes in the grain constituents have also been documented. But these cannot explain, for instance, why a pregelatinized product like parboiled rice should take actually a longer time to cook when compared to raw rice. Nor do they explain why parboiled rice is harder and less sticky after cooking. In other words, while changes in several individual

grain constituents have been studied by a number of workers, an integrated picture of the totality of these changes and the nature of the product is still not available. It was with this background that the present studies were undertaken. The object was to study the broad changes taking place in the grain during the parboiling process and to explain the behaviour of the resultant rice.

2.0. SCOPE OF THE WORK

One peculiar property of parboiled rice, as stated earlier, is that it takes a longer time to cook than raw rice, in spite of its being a precooked and gelatinized product. Detailed investigations on the hydration behaviour of parboiled rice at various temperatures were undertaken to see whether some light could be thrown into this paradox.

Similarly, ROBERTS et al (1954) reported that the starch-iodine blue value of rice increased on parboiling and was proportional to the severity of heat treatment. This value was determined by them by extracting rice flour in warm water. Inasmuch as the so-called starch-iodine blue value is nothing but the water-soluble amylose content of rice, the effect of extracting temperature and processing condition of the sample on amylose solubility was studied.

The pattern of degradation of rice grain in dilute alkali solution is a well-known test for rice quality. This

test was applied by RAGHAVENDRA RAO & JULIANO (1970) to parboiled rice, but with indifferent results. Being a pregelatinized product, it was felt that parboiled rice could behave differently than raw rice in alkali. Application of this test to parboiled rice prepared under varied conditions of processing was therefore explored.

Rheological properties of rice are expected to be altered after parboiling as a result of gelatinization, indications of which already exist in the studies of FERREL & PENCE (1964) and RAGHAVENDRA RAO & JULIANO (1970). Attempts were therefore made to study the changes in the viscographic characteristics of rice due to varied conditions of parboiling.

Meanwhile, it was observed that flaked or beaten rice, another processed-rice product, had some interesting properties. This product is essentially similar to parboiled rice, yet in striking contrast, it hydrates very easily. A comparative study of the different properties of the two forms of rice was therefore carried out. This study gave considerable insight into their nature and suggested that many of the properties of processed rice could be attributed to the occurrence or absence of starch reassociation or retrogradation.

The stage of occurrence of this starch reassociation, and the effect of various conditions, viz. moisture content, temperature and time of storage or drying on the onset,

promotion, retardation or reversal of the retrogradation phenomenon was then studied in detail.

Lastly, as the soaking step of parboiling resembles the early phase of germination of the seed, wherein a whole range of biochemical activity is known to become initiated, and as there existed a report of an increased sugar content in milled parboiled rice than in milled raw rice, some studies were undertaken on the changes of free sugars and amino acids during the parboiling process.

3.0. GENERAL MATERIALS AND METHODS

3.1. Paddy

A local tall *indica* nonwaxy variety, Ratnachudi (S 749), was used throughout. It was a medium-fine grain rice, with mean dimensions of the milled rice as follows:

length = 5.6 mm,
length/breadth = 2.5,
grain weight = 15.2 mg.

Samples were procured either from a nearby Agricultural Research Station at Nagenahalli, or in a few cases from the market, from time to time during the course of work.

Other varieties were also used for comparative purposes at certain stages. These were all procured from the experiment station.

The paddy samples were fumigated and then stored in closed 12-kg capacity metal containers in the laboratory. As

stored, their moisture contents lay in the range of 10-13% (wet basis).

All experiments were usually carried out at ½-2 yr age of the samples reckoned from harvest.

3.2. Parboiling

Parboiled rice with different conditions of soaking and steaming was prepared by the general method of BHATTACHARYA & SUBBA RAO (1966a) as follows:

3.2.1. Soaking: Paddy was soaked at different temperatures as desired. The time of soaking was usually adjusted to the optimum for that temperature (i.e., the minimum time necessary to give a finished rice -- after steaming, drying and milling the paddy -- without any ungelatinized core or white belly).

For some experiments, soaking was done for three periods each. In such cases, the middle period corresponded to the optimal soaking time at that particular temperature, the other two representing under- and over-soaking respectively.

Paddy (2-3 kg) was soaked in tap water in an aluminium vessel provided with a stirrer and a thermometer. Heat was provided by bunsen burners from below, the temperature being maintained (± 1°C) by adjusting the burners. For soaking at 37°C, paddy in water was brought to 37°C, covered with a tight-

fitting lid and kept in a chamber maintained at that temperature.

An alternate procedure most commonly adopted for the work was to put the paddy in hot water such that the temperature after mixing paddy was 70-75°C. The mixture was then left overnight (about 18 hr) at room temperature after covering the vessel with jute bags (BHATTACHARYA & INDUDHARA SWAMY 1967). This method is designated here as RT' soaking. The method allowed a sufficiently rapid hydration, but without requiring any particular care. Being at a fairly high temperature and for a short period, it avoided the fermentation of room-temperature (RT) soaking; yet, as the temperature dropped quickly below the gelatinization point, it simulated RT soaking with reference to effect on rice quality.

3.2.2. Steaming: After soaking, the excess water was drained off and the paddy was spread on a wire-mesh tray. It was then steamed in an autoclave directly connected to a steam line for the desired time. All steaming in the present studies was carried out at atmospheric pressure (i.e. 0 psig). For usual purposes, steaming was done for 10 min. But steaming for 2-60 min was also resorted to.

In certain experiments, to study the effect of mere soaking, half the soaked paddy was directly shade dried (and milled) without steaming.

3.2.3. Drying: All samples of parboiled paddy were dried in the shade in the laboratory at room temperature (RT: 23-32°C) for 1-4 days, till their moisture contents dropped to 10-13% (wet basis).

3.2.4. Parboiled rice from presteamed paddy: A few batches of parboiled rice were prepared using paddy that had been presteamed (15 min at 0 psig) and shade dried before parboiling. This simulated the traditional 'double-boiling' method of parboiling.

3.3. Milling

Paddy was shelled in a laboratory model McGill Sample Sheller. The resulting brown rice (100-110 g) was milled in a McGill Miller No.1, under medium to heavy pressure applied manually or mechanically (the latter after suitable modifications of the equipment (BHATTACHARYA & SOWBHAGYA 1972a) and in later parts of the studies). Brown rice from raw and merely soaked paddy was milled till whitish powder issued through the mill-screen. In case of parboiled paddy, the brown rice was mixed with 10 g of its own husk and milled till nothing issued from the mill-screen. The resultant milled rice was considered as 'full milled' and corresponded approximately to 7-9% degree of milling (d.m.).

For studying the effect of d.m. (percentage by weight of brown rice removed as bran on milling), dehusked brown rice,

free from paddy, was milled to different degrees by application of different pressures and time. The d.m. was determined by weighing the bran after passing through a 16-mesh sieve (BHATTACHARYA & SOWBHAGYA 1972a).

3.4. Grinding

The rice was ground in a hand-operated coffee grinder or in an electric disc grinder (Buhler, type MLI 204) to pass through 45-mesh sieve.

For viscography, the 45-mesh flour was further ground in a Raymond Mill (a high-speed hammer mill) to yield a roughly 65-mesh flour.

In certain experiments, the 45-mesh powder was macerated in a glass mortar and pestle to give the desired mesh size.

3.5. Moisture Content

Moisture content of the samples was determined by heating in an air oven at 105°C for 20 hr in an aluminium moisture dish. A correction factor of 0.4% moisture (dry basis) for powder, 0.5% for rice and 1% for paddy was added to the calculated value of percentage loss in weight, to account for the error of incomplete drying under these conditions as compared to drying in a vacuum oven after grinding (Y.M. INDUDHARA SWAMY, CFTRI Mysore, unpublished).

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C h a p t e r III

HYDRATION CHARACTERISTICS OF PARBOILED RICE

1.0. INTRODUCTION

As reviewed earlier, it has been repeatedly observed that, in boiling water, parboiled rice hydrates at a slower rate than raw rice and therefore takes a longer time to cook. Moreover, this increase in cooking time is proportional to the severity of heat treatment (KURIEN et al 1964, BHATTACHARYA & SUBBA RAO 1966b, DIMOPOULOS & MULLER 1972, ARAI et al 1975, PRIESTLEY 1976a, ALI & OJHA 1977). In other words, the greater the extent to which rice is precooked (for that is essentially what parboiled rice is), the harder it is to re-cook it later! There is as yet no explanation for this paradox.

Meanwhile an accidental finding by us added further to the complexity of the situation. When put in water at room temperature, it was surprisingly noted (see section 3.3) that parboiled rice now seemed to hydrate faster and to a greater extent than raw rice!

It was therefore decided that a detailed study of the hydration characteristics of parboiled rice at different temperatures and for different time durations was called for.

Since it has been repeatedly noted that hydration, and in fact all properties, of parboiled rice are strongly affected by the degree of heat treatment during processing, parboiled rice prepared under different conditions of processing, ranging from very mild to very severe degrees of heat treatment, was included in the study. This was expected to help in a better understanding of the changes brought about during the parboiling process.

2.0. MATERIALS AND METHODS

Ratnachudi paddy purchased from the local market and stored in the laboratory for nearly 2 yr was used. Procedure of parboiling and milling have been described in Chapter II.

2.1. Water Uptake

Milled rice was first exposed for 1-2 days in a constant-temperature and humidity room (temperature about 28°C, RH about 65%), to equalize the moisture in different samples prior to experiment (final moisture content, about 13.0%, wet basis). A 15 x 200 mm corning test tube, containing approximately 20 ml of distilled water and covered with a glass cuvette, was previously heated to the desired temperature by being immersed in a thermostatic or boiling water bath (bath

temperature about 0.5°C higher than the desired cooking temperature). About 2.00 g of unbroken sound grains of rice, accurately weighed, was added into the tube, and the rice was stirred momentarily with a wire (which was kept immersed in the bath) to dislodge any air bubble. After hydrating for the desired period in the bath, the tube was removed, immersed in tap water for 1 min, and the contents were strained through a wire strainer. The rice was quickly spread on a double-fold filter paper (Whatman No.1) and pressed with another double-fold filter paper to remove the adhering moisture, and weighed. Its moisture content was then determined as described in Chapter II.

The apparent water uptake (W', g/g) was determined by dividing the weight of water absorbed by the weight of the original rice:

$$W' = \frac{w_f - w_o}{w_o}$$

where w_f and w_o are the final and original weights of the rice. The true water uptake (W, g/g), corrected for the solids lost in the gruel, was calculated from the formula (BHATTACHARYA & SOWBHAGYA 1971)

$$W = \frac{M_f - M_o}{1 + M_o}$$

where M_f and M_o are final and original moisture contents (g/g, dry basis). As the W'/W ratio was found to vary with the

severity of parboiling, the W values had to be used here.*

2.2. Loss of Solids during Cooking

Loss of solids into the gruel (excess cooking water) during cooking of rice (s) was calculated from the true and the apparent water uptake values (W, W') as per the following formula (INDUDHARA SWAMY et al 1978):

$$s\ (\%) = \frac{W - W'}{1 + W} \times 100$$

2.3. Equilibrium Moisture Content attained by Rice upon Soaking in Water at Room Temperature (EMC-S)

Whole-grain rice (about 3-5 g) was put under about 50 ml water taken in a 100 ml beaker, covered with a Petri dish, and left aside. The rice was strained through a wire strainer after about 24 hr, and thoroughly pressed between Whatman No.1 filter paper sheets to remove all adhering moisture. The moisture content of the rice was determined. This value was expressed as the EMC-S, as several preliminary experiments revealed that milled rice under above conditions attained an equilibrium with respect to moisture after 6-8 hr (see Fig. 7).

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* This is not the case in raw rice, where the ratio is relatively constant from variety to variety, so that the W' values give the same pattern of results as W values (BHATTACHARYA and SOWBHAGYA 1971).

3.0. RESULTS

3.1. Water Uptake at Different Temperatures

3.1.1. Preliminary study with various samples: The hydration of a number of variously parboiled milled rice samples when cooked at different temperatures (room temperature, 60°, 70°, 80°, 90° and 96°C) for 10 min was first studied. The results (not presented) brought out two points.

Firstly, there were clearly two patterns of hydration, one at low temperatures (where parboiled rice hydrated more) and another at high temperatures (where raw rice hydrated more). Secondly, this divergence increased with increasing severity of heat treatment (i.e. with increasing time and temperature of soaking and time of steaming) of the paddy during processing.

3.1.2. Detailed study at different temperatures and for different times: The hydration characteristics of three representative samples were therefore studied in greater detail at different temperatures and for different times. The three samples were: raw (R), mildly parboiled (M-PB -- RT' soaked paddy steamed for 10 min), and severely parboiled (S-PB -- RT' soaked paddy steamed for 60 min) rice. The results are presented in Fig. 5.

At 60°C, raw rice (R) hydrated only marginally and attained more or less an equilibrium after about 1 hr. Mild parboiled rice (M--PB), on the other hand, continued to absorb

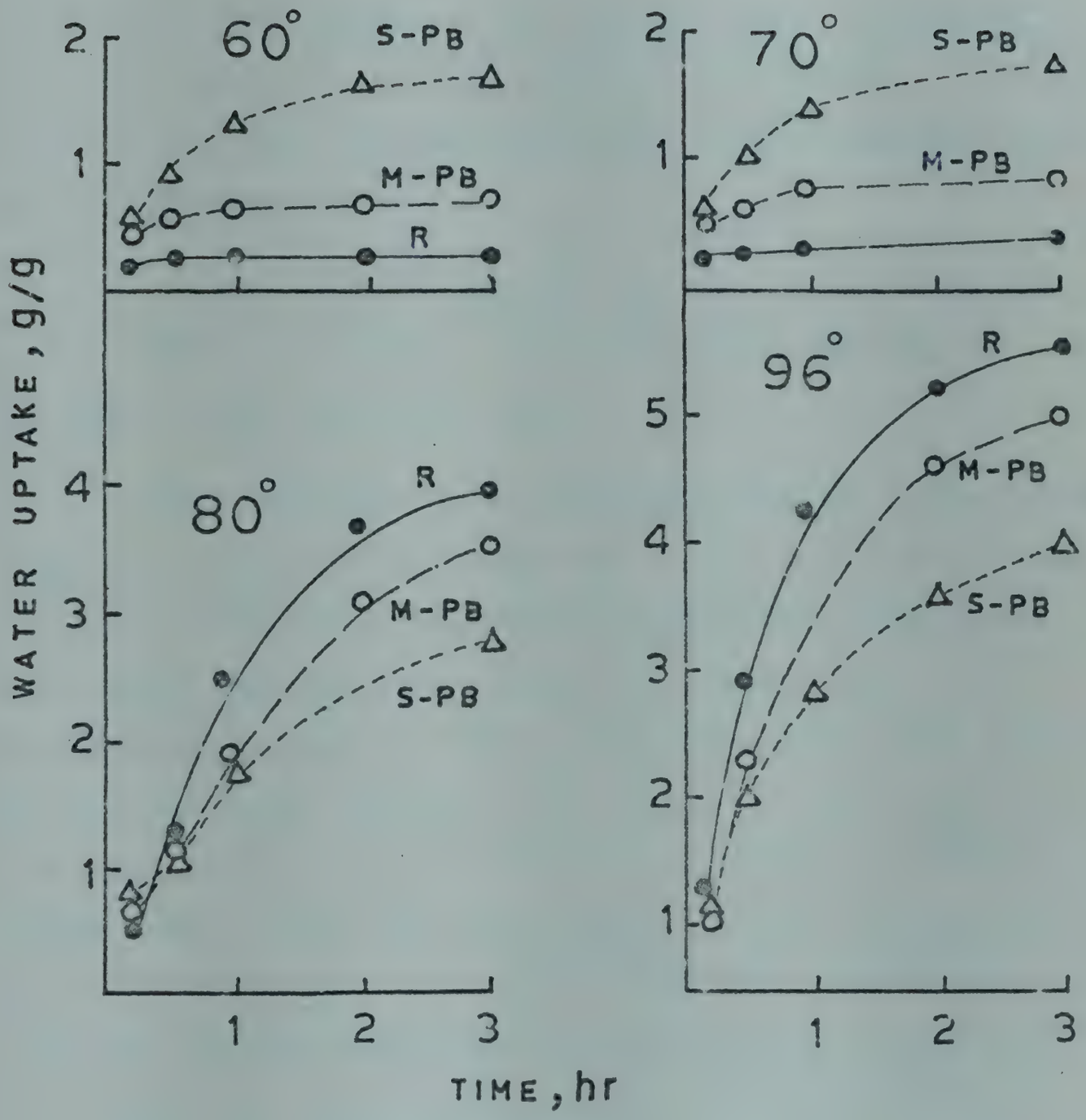


Fig. 5. Water uptake of raw (R), mild (M-PB) and severe parboiled (S-PB) rice vs. time of cooking at different temperatures.

moisture for a longer period, and the final amount of water absorbed was much higher. The rate and extent of absorption was still higher in severely parboiled rice (S-PB). At 70°C cooking, the trend was essentially same except that the actual values were slightly more.

At 80° and 96°C, however, the pattern was quite the reverse (more so at 96°C). The water uptake now was the highest in R and lowest in S-PB.

This reversal of the hydration behaviour in the three samples is more clearly brought out in Fig. 6, where the same data are plotted with temperature as abscissa. The curves also reveal that for each duration of cooking there was a temperature at which the water uptake was more or less identical for the three samples. This temperature value gradually decreased as the time of cooking was increased, and finally became more or less constant at about 78°C (for cooking periods of 30 min and more). This "iso-water-uptake temperature" is evidently closely related to the gelatinization temperature of the sample, and hence would presumably vary from variety to variety.

It can be concluded from the above results that at temperatures roughly below the gelatinization point of the variety, parboiled rice hydrates faster and to a greater extent than raw rice, the rate of hydration moreover increasing with increasing severity of parboiling. On the contrary, at

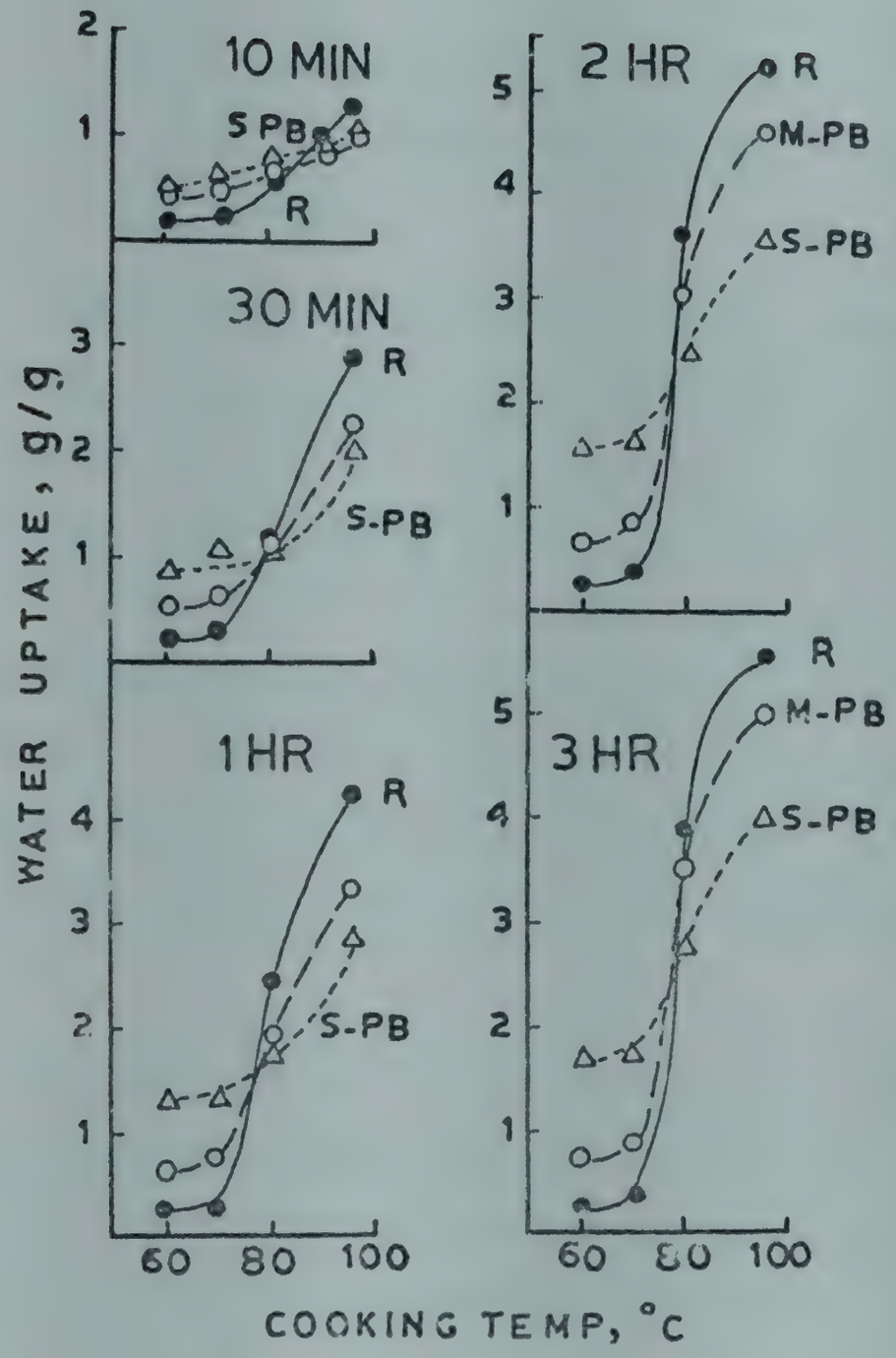


Fig. 6. Water uptake of raw and parboiled rice vs. temperature of cooking for different periods.

temperatures above this point, the hydration follows a precisely reverse pattern. Also, the greater the departure of the test temperature from the transition point, the greater is the difference in hydration rates among samples of different severity of parboiling.

The results further show that water uptake values at 60° and 96°C could serve as very good tests of parboiled rice as well as of the severity of parboiling. These should best be determined after cooking for 1-2 hr, as Fig. 6 shows that the water uptake curves tend to reach a plateau and show the maximum differentiation after cooking for 2 hr at various temperatures. This would give a much better test than cooking at 96° for 15-30 min as has been the practice so far (KURIEN et al 1964, BHATTACHARYA & SUBBA RAO 1966b, DIMOPOULOS & MULLER 1972).

However, a still more sensitive test would be given by expressing the two values above as a ratio (W_{60}/W_{96}). In other words it will show how much a particular sample is able to hydrate at 60°C when compared to that at 96°. This proportion would be least in raw rice (about 5%) and the highest in severely parboiled rice (about 50%).

3.1.3. Study of the effect of processing conditions: The above water-uptake value indices (W_{60}, W_{96}, W_{60}/W_{96}) were then used as tools to study the effect of processing conditions on the quality of rice. Results are shown in Table 3.

Table 3

Water uptake of raw and parboiled rice at 60° & 96°C (2 hr each)

Condition of parboiling			Water uptake[a] (% of raw)				W_{60} / W_{96} (%)	
Soaking		Steaming	60°		96°			
Temp. (°C)	Time (hr)	time (min)	Rice milled from paddy					
			Merely soaked	Parboiled	Merely soaked	Parboiled	Merely soaked	Parboiled
--- Raw rice --			100(0.23)		100(4.69)		4.9	
RT'	18[b]	2	109	208	103	95.4	5.2	10.7
		10		284		85.6		15.8
		60		613		75.6		40.3
37	15	10	104	251	98	94.0	4.8	12.2
	30[b]	10	102	280	101	94.6	4.4	13.4
	50	10	102	298	98	89.8	4.8	15.1
60	2.5	10	102	249	100	91.1	4.8	12.4
	5.5[b]	2	120	214	98	94.4	5.6	10.7
		10		296		88.6		15.8
		60		495		77.6		30.2
	9	10	125	346	95	84.1	5.8	18.6
70	3.75[b]	2		236		92.3		12.3
		10		382		83.0		21.8
		60		585		73.6		37.6
	5.5	2		283		92.6		14.5
		10		435		84.0		24.4
		60		689		74.0		43.0
80	1	10	145	308	100	89.0	6.6	15.7
	2.5[b]	2		369		80.6		21.6
		10		486		76.6		30.0
		60		658		69.0		45.0
	1.5[c] (+1.0)	2		315		82.4		18.1
		10		420		78.8		25.2
		60		559		67.9		38.9
	3.5	10	690	804	81	71.2	38.6	51.4

Contd.

a/ All water uptake values are expressed as the % of raw rice at the same temperature. The actual water-uptake values of raw rice are given in parentheses against the sample Raw.

b/ These values represent the optimum times of soaking at the respective temperatures.

c/ In this case, paddy was soaked at 80° for 1.5 hr, drained, and tempered at the same temperature for 1 hr. Moisture content was 32.9%. It showed optimum soaking, without any white belly or deformity after steaming and milling. Soaking at 80° for 2.5 hr (which was the optimum time for continuous soaking), on the other hand, gave excessive bursting and deformity. Moisture in this case was 36.5%.

Mere soaking of paddy upto temperatures of 60°C did not have any appreciable effect on the hydration of the resulting milled rice. High temperatures of soaking, on the other hand, showed its effect of gelatinization. Thus, mere soaking at 80° for optimal time (2.5 hr) produced the effect of mild parboiling, and over-soaking at this temperature produced quite severe parboiling. Steaming following soaking, even undersoaking, immediately showed its effect. Increasing degree of steaming affected the water uptake increasingly. It is also apparent from the two samples optimally soaked at 80° -- one soaked for 2.5 hr, moisture content 36.5%; another soaked for 1.5 hr and then tempered at the same temperature for 1 more hour, moisture

32.9% -- that a higher moisture content in the sample being parboiled, other things being equal, gave a higher degree of gelatinization.

It will be noted that the present indices revealed the effects of different conditions of soaking and steaming much better than observed earlier by BHATTACHARYA & SUBBA RAO (1966b) after cooking at 96° for 20 min only.

3.1.4. Effect of presteaming of paddy and of soaking in presence of chloramphenicol: A few experiments were carried out with rice prepared from paddy which had been presteamed before parboiling (the process being thus similar to the "double boiling" process in the industry). These samples gave somewhat lower water-uptake values, particularly at low temperatures of hydration, compared to corresponding samples parboiled without presteaming. These results are summarised in Table 4. Presteaming, thus, seems to have a cumulative effect in decreasing the water uptake of rice slightly, perhaps due to some reassociation of starch. But this subject was not further studied.

During the preparation of parboiled rice, it was observed that soaking of paddy at 37°C gave excessive fermentation and off-odour. For this reason, a duplicate series was prepared by soaking paddy in presence of chloramphenicol (100 µg/ml of steep water). The resultant rice was free from any off-odour, but did not show any significant difference with respect to either water-uptake behaviour or EMC-S (hence data

Table 4

Water uptake of parboiled rice prepared from presteamed paddy

Sample [a]	Percentage decrease in values compared to corresponding normal parboiled rice		
	W_{60}	W_{90}	W_{60} / W_{96}
--- Raw [b] ---	3	-1	4
RT'-18-0	10	2	10
-10	1	0	1
-60	18	0	18
80-2.5-0	22	11	13
-10	22	2	17

a/ The code numbers give, in the order indicated: The temperature of soaking (°C), time of soaking (hr), and time of steaming (min).

b/ That is, rice milled from presteamed paddy without soaking and steaming.

not presented). Microbial fermentation of paddy during soaking thus appears to have no effect on the hydration behaviour of the resulting parboiled rice.

3.2. Solids Loss during Cooking

It is well known that the loss of solids during cooking decreases after parboiling (studied so far only at boiling

temperature). The present data (Table 5) showed that this is largely true even when the rice is cooked at 60°C. The nominal values at this temperature are no doubt larger than the value

Table 5

Loss of solids from raw and parboiled rice on cooking at 60° and 96°C (2 hr each)

Condition of Parboiling			Loss of solids (%)	
Soaking		Steaming time (min)		
Temp. (°C)	Time (hr)		60°	96°
------ Raw ------			2.3	19.0
RT'	18	2	2.8	17.6
		10	2.8	13.1
		60	3.0	10.2
60	5.5	2	3.3	16.8
		10	3.3	13.2
		60	2.9	10.0
70	3.75	2	4.0	15.6
		10	3.7	12.4
		60	4.1	9.8
80	2.5	2	6.8	12.5
		10	3.6	10.7
		60	5.0	10.0

for raw rice. However, it can be inferred from the data of BHATTACHARYA et al (1972b) -- where they found that the starch-

iodine blue value of the gruel increases exponentially with increase in water uptake -- that the loss of solids is proportional to the water uptake. Hence, in view of the large increase of the W_{60} after parboiling (Table 3), the small increase in solids loss is not so significant.

As expected, solids loss after cooking rice at both 60° and 96°C, in general, decreased with increasing temperature of soaking beyond 60°C and with increasing time of steaming.

3.3. Equilibrium Moisture Content on Soaking in Water at Room Temperature (EMC-S)

As mentioned earlier, it was accidentally discovered in this laboratory that, contrary to the experience in boiling water, at room temperature parboiled rice hydrated faster and more than raw rice (INDUDHARA SWAMY et al 1971). When put under water at RT, rice reached essentially an equilibrium after 6-8 hr, but the equilibrium point was more in parboiled than in raw rice (Fig. 7). It was therefore realised that the EMC-S test could be a simple but sensitive test of parboiled rice.

The EMC-S of parboiled rice prepared under various conditions of soaking and steaming are presented in Table 6. It is quite apparent that EMC-S can not only differentiate between raw and parboiled rice but also between parboiled rices having different severity of heat treatment.

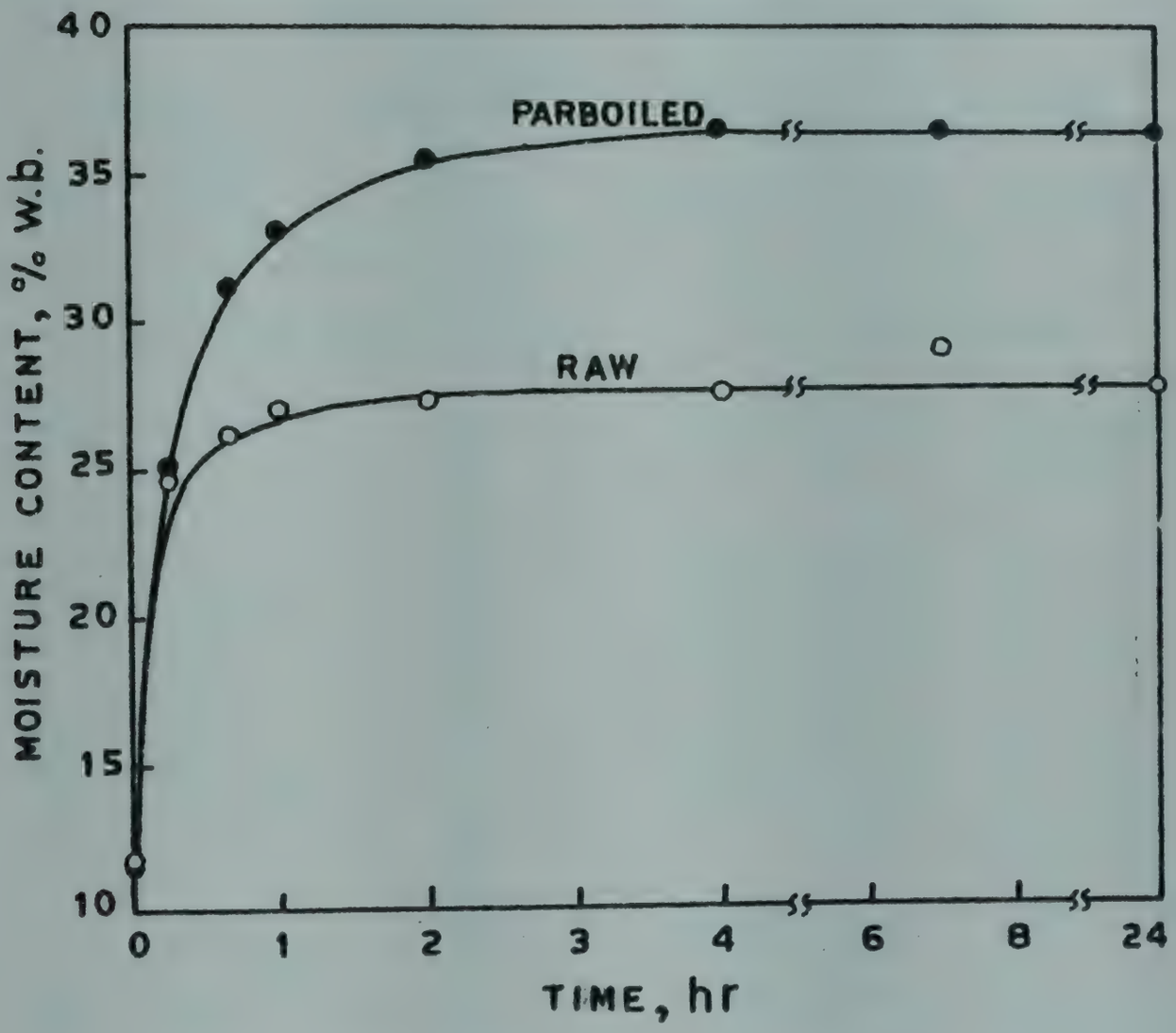


Fig. 7. Hydration of raw and parboiled rice at room temperature.

(Parboiled: RT' soaked, steamed 10 min)

Table 6

Equilibrium moisture content on soaking in water at room temperature (EMC-S) of raw and parboiled rice

Condition of parboiling			EMC-S (%, wet basis) [a]	
Soaking		Steaming time (min)	Rice milled from paddy	
Temp (°C)	Time (hr)		Merely soaked	Parboiled
--- Raw rice ---			27.6 (38.2)	
RT'	18 [b]	2	27.9 (38.7)	35.7 (55.6)
		10		38.8 (63.4)
		60		48.8 (95.4)
37	15	10	27.5 (37.9)	38.7 (63.2)
	30 [b]	10	27.9 (38.7)	40.1 (67.1)
	50	10	27.9 (38.7)	40.2 (67.3)
60	2.5	10	30.1 (43.1)	38.0 (61.3)
	5.5 [b]	2	29.8 (42.5)	35.9 (56.0)
		10		39.8 (64.1)
		60		45.9 (84.8)
	9	10	30.0 (42.9)	40.0 (66.6)
70	3.75 [b]	2	29.9 (42.6)	37.5 (60.0)
		10		42.2 (73.1)
		60		47.2 (89.5)
	5.5	2	33.5 (50.4)	38.2 (61.9)
		10		46.6 (87.4)
		60		48.0 (92.4)
80	1.0	10	32.1 (47.3)	39.4 (65.0)
	2.5 [b]	2		42.0 (72.5)
		10		45.2 (82.5)
		60		49.0 (96.1)
	3.5	10	52.5 (111)	52.3 (110)

[a] The values in parentheses give the EMC-S on dry basis.

[b] Optimum times of soaking at the corresponding temperatures.

The results followed a pattern more or less similar to water-uptake data at 60°C. The EMC-S of rice obtained from paddy merely soaked upto 60°C was only marginally more than that of raw rice. On steaming after soaking, the EMC-S of resultant rices perceptibly increased depending upon the duration of steam treatment. When the paddy was merely soaked at 80°, the EMC-S of the resultant rice was substantially more than that of raw rice and increased with increasing period of soaking -- showing the effect of gelatinization by mere soaking at this temperature. As a result of this substantial gelatinization during soaking itself, steaming after soaking at 80° (particularly when oversoaked), did not increase the EMC-S as much as before. The results of 70° soaking were in between the above two patterns. Here also the EMC-S of rice increased slightly on prolonged soaking.

4.0. DISCUSSION

It is clear that the hydration behaviour of parboiled rice is much more complex than previously thought. While parboiled rice no doubt hydrates at a slower rate than raw rice at the boiling temperature, it actually hydrates faster than the latter at lower temperatures. In fact, there is a transition point around the gelatinization temperature of starch, at which point the rate of hydration is identical for both; it is higher for parboiled rice than raw rice at lower temperatures, but higher for raw rice at higher temperatures. The greater the

departure from this transition temperature, the greater is the above difference. Besides, the greater the severity of heat treatment during parboiling, the greater again is the above difference.

The only explanation for the above paradoxical behaviour seems to be that, while the primary effect of parboiling is the gelatinization of the starch, a part of the gelatinized starch probably reassociates, or retrogrades, later.

The effect of gelatinization is obvious. Any treatment of the paddy that did not induce gelatinization, had little effect on the hydration -- e.g. mere soaking of paddy at 60°C or below. But gelatinization immediately changed the hydration behaviour, e.g. mere soaking of paddy at 70° and above or steaming following soaking. But the peculiar reversal of the hydration rate of the milled rice depending on the temperature of its cooking can only be explained by assuming that a part of the starch retrogrades following its gelatinization. These hypotheses could explain all the above behaviours.

Thus, at low temperatures, parboiled rice hydrates faster and to a greater extent than raw rice, because of its gelatinized starch component. It is well known that pregelatinized starch hydrates easily at room temperature, while raw starch does not (POWELL 1967). The greater the severity of parboiling, the greater is the degree of gelatinization, and hence the greater is the hydration of the rice at low temperatures.

When cooked at a high temperature, however, raw rice gets gelatinized as it is being cooked. It therefore hydrates fast. Moreover, its freshly gelatinized starch is free from starch retrogradation and hence its hydration power remains unimpaired. In parboiled rice, on the other hand, a part of the gelatinized starch (let us assume) is retrograded. Retrograded starch, like native starch, having a low power of hydration (POWELL 1967, COLLISON 1968), this retrogradation would therefore reduce the overall hydration of the grain compared to raw rice. Increased degree of pregelatinization probably induces a greater degree of retrogradation and thus is reflected in still lower hydration of the grain when cooked at a high temperature. The more the departure of the cooking temperature from the gelatinization point and the severer the heat treatment during the process of parboiling, the larger would be the difference between the hydration properties of raw and parboiled rice.

The above hypothesis is in agreement with the observed behaviour of pregelatinized starch, which hydrates more easily at lower temperatures compared to untreated starch, but whose swelling power at high temperatures is lower than untreated starch (POWELL 1967).

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Chapter IV

AMYLOSE-SOLUBILITY BEHAVIOUR OF PARBOILED RICE

1.0. INTRODUCTION

ROBERTS et al (1954) observed that the starch-iodine blue value of an warm-water extract of rice flour from parboiled rice was higher than that from raw rice. This value, further, increased with increasing severity of heat treatment during parboiling. The extraction temperature used by these authors was rather low (55°C water, left at room temperature for 1.25 hr). This test, modified by using a higher temperature of extraction, has been subsequently developed by other workers into a standard test for raw rice quality (HALICK & KENEASTER 1956, HALL & JOHNSON 1966, JULIANO et al 1968, BHATTACHARYA et al 1972b).

A little reflection would show that the so-called starch-iodine blue value was nothing but the amylose content of rice flour that dissolved out in water under the conditions of the test. On this logic, BHATTACHARYA et al (1972b) expressed the blue value of different rice varieties (raw) as water-soluble amylose, and found that this gave extremely valuable information. It was therefore felt that the blue value of parboiled rice also should be expressed in the same way to see whether it gave any additional information.

Secondly, in line with the experience with water uptake of parboiled rice as presented in Chapter III, it was felt that determining the blue value (i.e. soluble amylose) too at different temperatures might give additional useful information.

2.0. MATERIALS AND METHODS

The paddy and the procedure of parboiling, milling and grinding have been described in Chapter II.

2.1. Starch-iodine blue Value or Soluble Amylose content (sA)

Conditions of this test were thoroughly investigated. The fundamental steps of the test used were the same as those of ROBERTS et al (1954) -- viz. extracting rice flour in hot water and measuring the blue colour in an aliquot of the extract after acidifying and adding iodine solution.

2.1.1. Investigations: Initial experiments were carried out with a 45-mesh flour (successively ground in a hand mill using a 45-mesh screen) by the modified method described by BHATTACHARYA et al (1972b). However, it was observed in preliminary work that the sA was very sensitive to the particle size of the flour, increasing with its increasing fineness (Table 7).

Since parboiled rice was harder than raw rice and the hardness increased with the severity of parboiling, it was thought that the particle-size distribution in the nominally 45-mesh flours could be different in the different samples

Table 7

Effect of particle size on the water-soluble amylose content of parboiled rice [a/]

Conditions of parboiling		Soluble amylose (% of total amylose) [b/]		
Soaking temp. (°C)	Steaming time (min)	45 mesh	85 mesh	100 mesh
------ Raw -------		1.0	1.2	2.2
70	0	1.0	1.8	2.9
	2	1.2	-	2.8
	10	1.5	3.4	4.9
	60	1.8	4.1	5.1

a/ Extracted at 60° for 1 hr
b/ Total amylose = 30.2% (d.b.)

(i.e. finer fractions could be progressively reduced with increased severity of parboiling). If this was true, it would severely affect the results in view of the influence of particle size observed above.

To avoid this possible error, it was decided to carry out the test with a much finer flour where, it was hoped, the inter-sample differences in particle size would be negligible. Two procedures were adopted. Initially an 85-mesh flour was used, obtained by successively macerating a small portion of 45-mesh flour in a glass mortar and pestle till the entire quantity passed through 85-mesh screen. But this was very

laborious. Hence, the later experiments were done with a 60-mesh flour. This was obtained by passing the coarse flour through a Micro Wiley Mill, fitted with a 60-mesh delivery tube, and after adjusting the motor speed in such a way that final particle-size distribution in raw and differently parboiled sample remained more or less the same.

2.1.2. The final procedure: On the above basis, the final test procedure adopted was as follows:

One hundred milligrams of 85- (or 60-) mesh rice flour was taken in a 100-ml conical flask and wetted with 0.5 ml alcohol. Distilled water (49.5 ml) was added and the flask, covered with a glass bulb stopper, was heated in a water bath at the desired temperature (bath temperature 1°C more than the desired temperature). The time of heating adopted was 20 min at 96°, 40 min at 80°, 1 hr at 50° and 60°C, and 2 hr at RT -- which gave optimum colour readings as determined in preliminary studies. The flask was cooled in tap water and the extract was filtered through Whatman No.1 filter paper, discarding the initial 10-15 ml. Colour was developed in a suitable aliquot of the filtrate after adding appropriate quantities of 15% HCl and 0.2% iodine solution (in the ratio of 1 ml of HCl and 2 ml of iodine per 100 ml of final colour solution). The colour was read in a Klett-Summerson photoelectric colorimeter with a No.60 filter. Extraction and reading as above were carried out in duplicate and the mean value was taken.

Subsequently, sA was also determined in the excess water remaining after allowing the whole grains (2 g/20 ml) to hydrate as in water-uptake studies at 60°C (Chapter III). A standard amylose (Nutritional Biochemicals Corp.) solution was included in all the experiments, and all results were expressed as soluble amylose content as % of the total amylose in the rice (BHATTACHARYA et al 1972b). This way of expression gave, at a glance, the additional information of the solubility of amylose in the various samples and at the various experimental conditions.

2.2. Amylose Content

The total amylose content of rice was determined in defatted rice flour as per the procedure of SOWBHAGYA & BHATTACHARYA (1971). This value was 30.2% amylose (dry basis) in raw rice, and did not seem to be affected by any condition of parboiling.

3.0. RESULTS

3.1. Total Amylose Content

The total amylose content of rice, as mentioned above, seemed to remain unchanged by parboiling as tested in several samples.

3.2. Soluble Amylose Content

3.2.1. Effect of temperature of extraction: Coming to the soluble amylose content (sA), the pattern of results bore a striking resemblance to the water-uptake data discussed in Chapter III. In any sample, the sA value increased markedly

with increasing temperature of extraction of the flour from room temperature (27°) to the boiling temperature (96°). But the pattern of this increase in different samples of rice was quite different, with the result that the relative values between raw and parboiled rice got reversed when going from low to high temperatures. One set of illustrative data is shown in Fig. 8 which at once shows the broad similarity to the water-uptake results (Fig. 6). The relative values among the samples were similar at 60° and below, but it was quite the reverse at 96°, 80°C being the transition point at which the sA was nearly identical in all samples.

3.2.2. Effect of processing conditions: Detailed results of a series of samples at two selected temperatures, 50° and 96°C, are given in Tables 8 and 9. Table 8 shows the effect of soaking and soaking + steaming separately and also the effect of varying the time of soaking during parboiling of paddy; Table 9 shows the effect of the time of steaming (at 0 psig) of paddy in particular.

As observed earlier, here again, soaking of paddy at 60° and below had little effect on the sA, while soaking at 70° and above, particularly oversoaking, immediately showed its effect due to gelatinization. Steaming of paddy following soaking, as expected, had a marked effect, and the effect increased with increasing time of steaming. The results of 80° soaking in Table 9 show, as already observed with water uptake, that the moisture content of paddy at the time of steaming

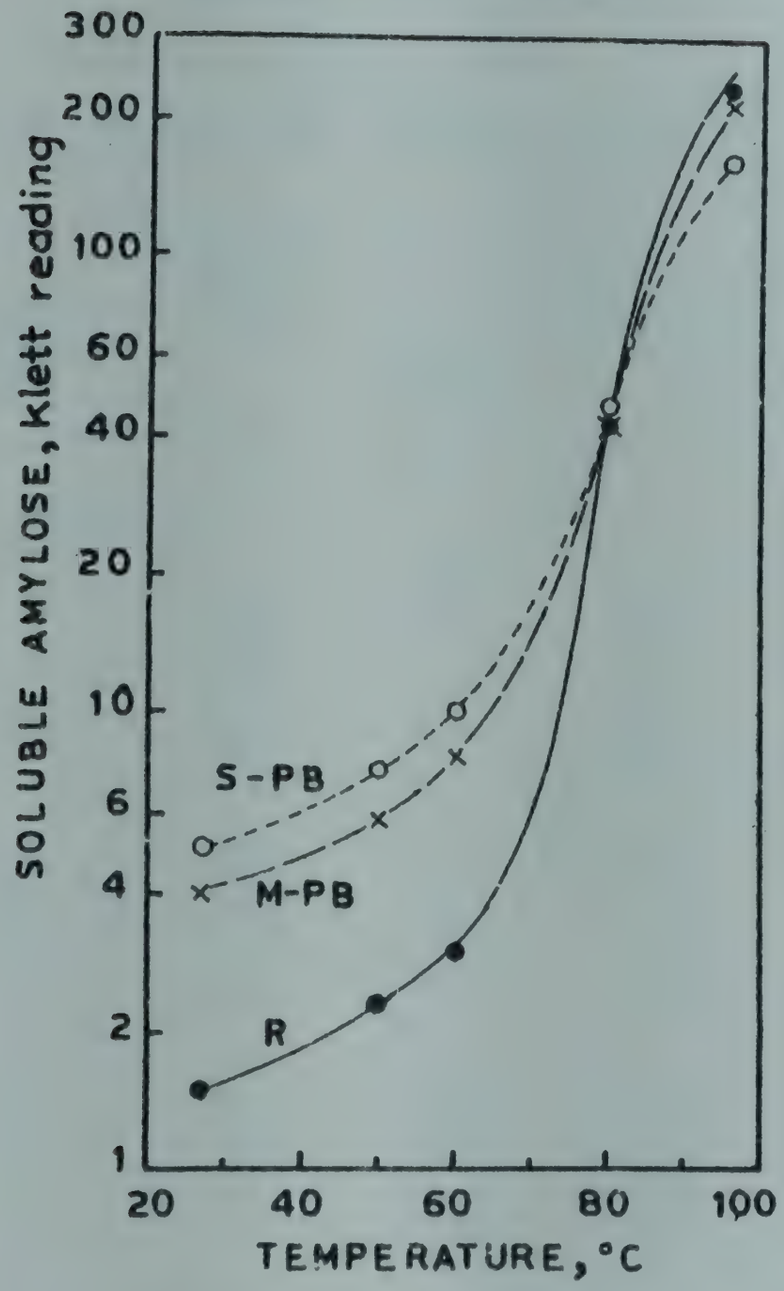


Fig. 8. Soluble amylose of raw (R), mild (M-PB), and severe parboiled (S-PB) rice at different temperatures.

(Extraction time: 20 min at 96°, 40 min at 80°, 1 hr at 60° & 50°C, and 2 hr at RT (27°). All Klett readings converted to identical amounts of flour)

Table 8

Water-soluble amylose content of raw and variously parboiled rice[a/]

Condition of parboiling			Soluble amylose (% of total amylose)			
			50°		96°	
Soaking		Steaming time (min)	In rice milled from paddy			
Temp. (°C)	Time (hr)		Merely soaked	Parboiled	Merely soaked	Parboiled
------- Raw -------			0.9		48.3	
RT'	18	2	0.9	1.5		47.0
		5		1.8		-
		10		2.1		-
		20		2.2		42.0
		40		2.2		-
		60		2.9		-
37	15	10	1.1	2.0	-	-
	30	10	1.2	2.4	-	-
	50	10	1.3	2.3	-	-
60	2.5	10	1.4	1.9	-	-
	5	10	1.6	2.3	-	-
	9	10	1.5	2.8	-	-
80	1	10	1.8	2.1	45.2	44.9
	2.5	10	2.1	5.1	44.9	31.6
	3.5	10	3.4	4.0	43.0	32.0

a/ Determined in 85-mesh flour

Table 9

Water-soluble amylose content of raw and variously parboiled rice[a/]

Condition of parboiling			Soluble amylose (% of total amylose)		
Soaking		Steaming time (min)			sA_{50}/sA_{96} (%)
Temp. (°C)	Time (hr)		50°	96°	
--- Raw ---			0.65	44.0	1.5
RT'	18	2	0.82	37.8	2.2
		10	0.94	37.1	2.5
		60	1.20	35.2	3.4
60	5.5	2	0.85	40.0	2.1
		10	1.01	37.4	2.7
		60	1.24	33.2	3.7
70	3.75[b/]	2	0.67	36.1	1.9
		10	0.95	31.2	3.0
		60	1.16	23.8	4.9
	5.5	2	0.85	36.1	2.4
		10	1.08	33.0	3.3
		60	1.39	20.9	6.6
80	1.5[b,c/] (+1.0)	2	0.81	32.1	2.5
		10	0.84	28.5	3.0
		60	1.24	23.2	5.4
	2.5[b,d/]	2	0.84	33.4	2.5
		10	0.97	28.1	3.5
		60	1.30	16.6	7.8

a/ Determined in 60-mesh flour.
b/ All represent optimum soaking time.
c/ Paddy soaked in water for 1.5 hr, water drained off, and paddy held at the same temperature for 1 hr. Moisture content, 32.9% (wet basis).
d/ Moisture content after soaking, 36.5% (wet basis).

probably influences the extent of gelatinization of the grain and hence the sA of the resultant rice. Both the paddy samples were optimally soaked (no white belly), but milled rice from the paddy sample with a higher moisture content at the time of steaming gave considerably higher sA at 60° and lower sA at 96°C as compared to the other sample.

It is clear that the sA value also can be used as a fairly sensitive test of parboiled rice, as well as of the degree of parboiling. Both the values of sA_{50} and sA_{96} can be used for this purpose, though, as in the case of water uptake, a more sensitive index is given by their ratio, viz. sA_{50}/sA_{96} (Table 9).

Another way of appreciating the above interrelations is to note the relationship between water uptake and the soluble amylose values. As shown in Fig. 9, the water uptake of the various samples at 60° and 96° (2 hr each) were closely related to sA_{50} and sA_{96} values of these samples, respectively.

3.2.3. Soluble amylose in gruel: It was subsequently noted that the water-soluble amylose content can be determined in whole grains as well, by determining the blue value of the gruel (excess cooking water) remaining after cooking of the rice. BHATTACHARYA & SUBBA RAO (1966b) showed that the gruel blue value of raw and variously parboiled rice are related to the corresponding water-uptake values of the samples when cooked at 96°C. Clearly then, from the relationship observed

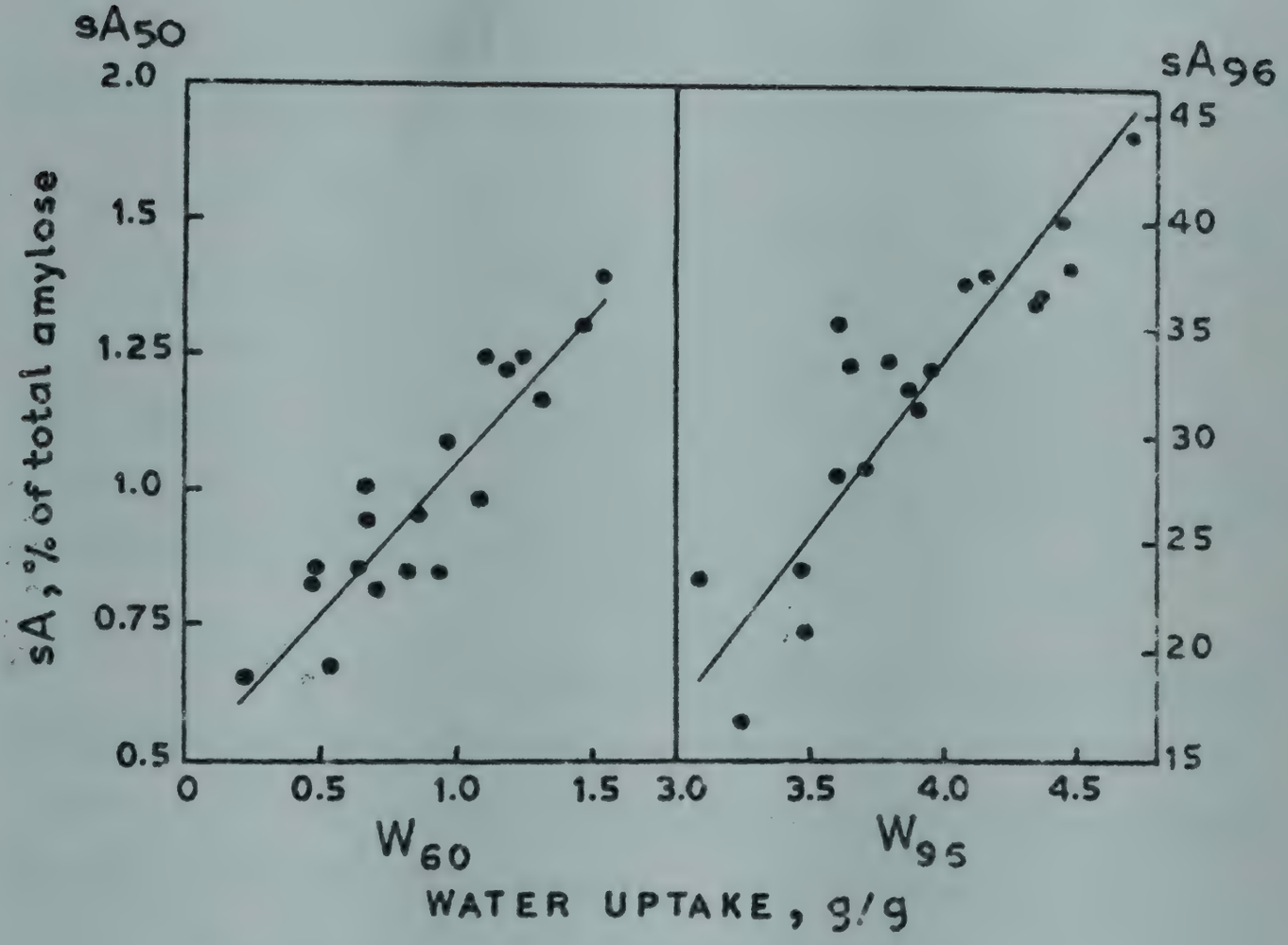


Fig. 9. Relationship between water uptake and soluble amylose content of raw and parboiled rice.

in Fig. 9, the gruel blue value at 96° from whole rice and the sA_{96} value determined in powders also should be positively related. Similarly, when the gruel blue values of the various whole rice samples cooked at 60°C for 2 hr were determined here, these values were found to be closely related to the sA_{50} values determined in powder (Fig. 10).

It must be mentioned, however, that the precision of the soluble-amylose determination, whether in powder or in whole grains, was less as compared to the determination of water uptake. As a test of parboiled rice, therefore, determination of soluble amylose content offers no additional advantage over the determination of water uptake.

3.2.4. Effect of presteaming of paddy and of soaking in presence of chloramphenicol: As in the case of hydration studies, a few experiments were carried out with rice prepared from presteamed parboiled paddy. These samples gave consistently lower sA, particularly when extracted at lower temperatures (Table 10). These results would probably suggest a certain amount of additional hardening, or starch reassociation, as a result of the presteaming.

Rice from paddy soaked at 37°C in presence of chloramphenicol solution, to control the excessive fermentation, also gave 20-25% lower soluble amylose at 60°C compared to the corresponding rice prepared by soaking in water without chloramphenicol (not shown). This raises the question whether a

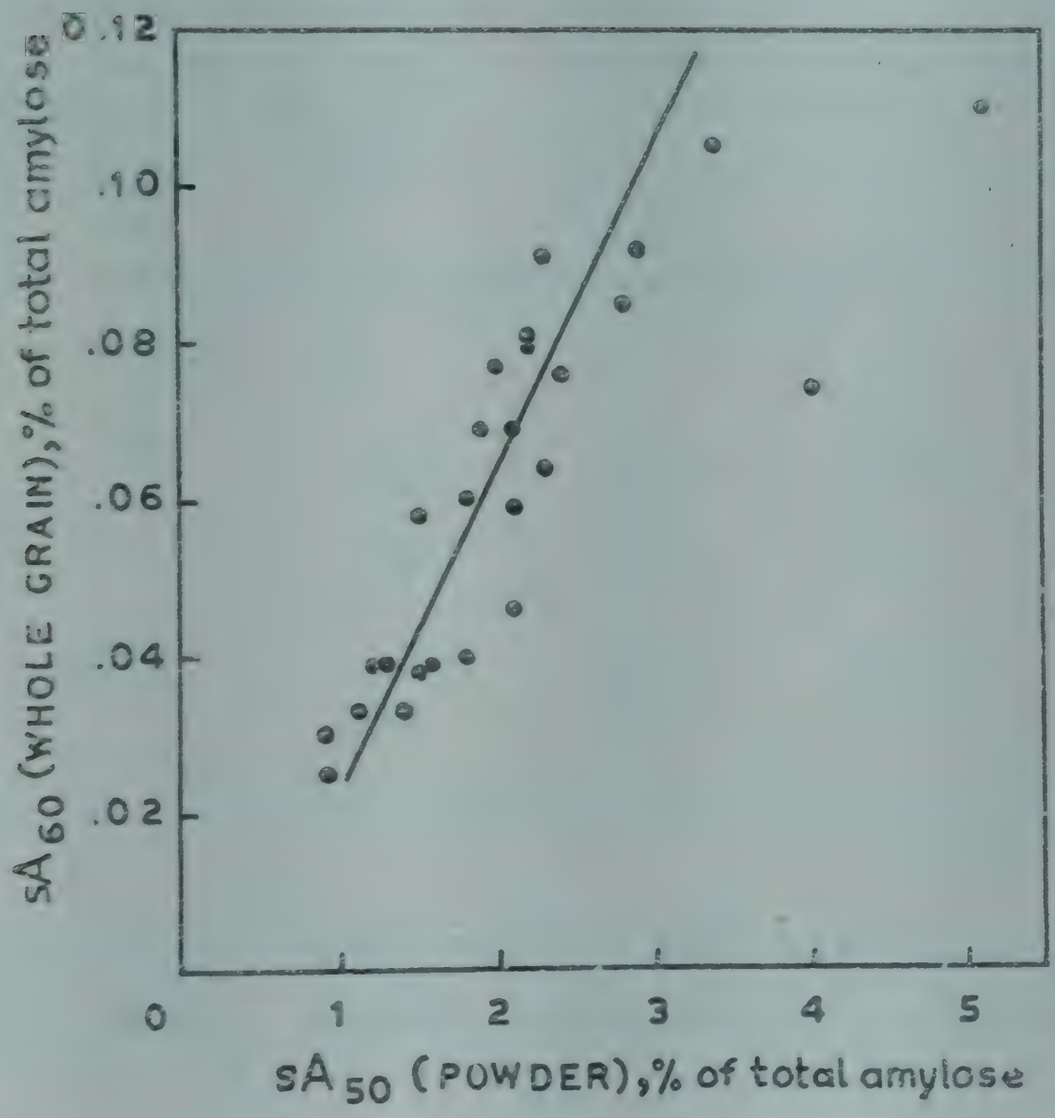


Fig. 10. Relationship between soluble amylose extracted from whole grain (sA_{60}, 2 hr) and from powder (sA_{50}, 1 hr).

Table 10

Water-soluble amylose content of parboiled rice prepared from presteamed paddy

Condition of parboiling			Percentage decrease in soluble amylose content compared to corresponding normal parboiled rice		
Soaking		Steaming time (min)			
Temp. (°C)	Time (hr)		50° (pdr)	60° (rice)	96° (pdr)
Raw			-	-	4
RT°	18	0	-20	-8	-
		10	15	20	-
		60	17	25	-
80	2.5	0	31	30	11
		10	39	37	7

part of increased soluble amylose after parboiling arose out of microbial action. However, this aspect was not pursued further.

4.0. DISCUSSION

At 50°C, in agreement with the observations of ROBERTS et al (1954), the water-soluble amylose content (sA) increased from raw to parboiled rice and with the increasing severity of parboiling. At 96°C, on the other hand, the soluble amylose content actually decreased, though slightly, from raw to parboiled rice, and proportional to its severity. Sieving the

flours in a 120-mesh screen, to remove the very fine fractions, did not alter these sA_{96} results (not shown) -- showing that it was not due to any possible difference in the particle-size distribution among the flours. On extraction at 80°C, as in the case of water uptake, the sA content too remained more or less constant in all the raw and parboiled samples under a particular set of experimental conditions.

These results probably indicate that the total soluble amylose content of a rice sample is the value given by extracting it at boiling temperature. This value definitely decreased slightly with parboiling. This decrease seems to suggest again some sort of reassociation or partial retrogradation of the starch in parboiled rice. On extracting at a temperature below the gelatinization point, however, only a part of the soluble amylose was extracted in the water, but this part was more in parboiled rice than in raw rice, increasing with the increasing severity of heat treatment during parboiling. This increase is evidently due to disruption of the starch granules caused by their gelatinization during parboiling.

The present results too thus suggest that the final properties of parboiled rice are a reflection of starch gelatinization on the one hand and its possible partial retrogradation on the other. At low temperatures of extraction, the gelatinized starch naturally gives a higher amylose solubility as compared to raw rice, and the value increases with increasing

degree of gelatinization, i.e. the increasing degree of parboiling. Upon extraction at high temperatures, however, the reassociated starch now makes its presence felt and leads to a lower solubility of amylose as compared to raw rice.

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Chapter V

DEGRADATION OF PARBOILED RICE GRAINS BY ALKALI

1.0. INTRODUCTION

The alkali reaction test of rice (LITTLE et al 1958, BHATTACHARYA & SOWBHAGYA 1972b) is a well-known test of rice quality. In this test a few grains of milled rice are immersed in a dilute alkali solution (1.4-2.0% KOH), when kernels of different varieties undergo different extents of degradation. The extent of degradation observed, expressed by a numerical score, has been found to be inversely related to the gelatinization temperature of the variety (JULIANO et al 1964, BHATTACHARYA et al 1978). Since then this test has been extensively employed in rice quality studies as an indirect estimate of gelatinization temperature.

RAGHAVENDRA RAO & JULIANO (1970) and ARAI et al (1975) applied this test to parboiled rice, but with inconclusive results. The former noticed that parboiled rice seemed to be degraded to a slightly greater extent when compared to raw rice, while the latter felt it was the reverse.

Preliminary studies by us showed that parboiled rice behaved quite differently in alkali than raw rice, because of which its reaction pattern could not be scored by the same score

card as for raw rice. In view of this, and in view of the earlier results of hydration and amylose solubility (Chapters III & IV), a detailed study on the subject was undertaken.

2.0. MATERIALS AND METHODS

2.1. Rice

Three *indica* rice varieties (Ratnachudi, Coimbatore Sanna, Halubbulu), 2 dwarf *indica* varieties (Taichung Native 1, IR 8), 2 *japonica* varieties (Taichung 65, Tainan 3) and one *indica* x *japonica* cross (ADT 27) were used. Detailed studies were conducted with Ratnachudi variety as usual, the others being used for comparison.

Methods of parboiling and milling have been described (Chapter II).

2.2. Alkali Test

This test was conducted as per the method of BHATTACHARYA & SOWBHAGYA (1972b). Six kernels of rice were immersed in 20 ml of potassium hydroxide solution of desired strength in a closed 7-cm dia Petri dish, placed on a black background. The pattern and extent of degradation were noted after various time periods. The concentration of alkali was adjusted by titration.

Use of sodium hydroxide was also tested. However, it was observed that the differentiation between various

samples was rather poor in this alkali. Hence its use was discontinued.

3.0. RESULTS

3.1. Reaction Pattern of Parboiled Rice

3.1.1. Difference from raw rice: Initial studies showed that the response of parboiled rice to alkali was of a quite different nature when compared to raw rice. Firstly, parboiled kernels started reacting in alkali soon after being immersed in the alkali solution, while raw rice took several hours to show an initial reaction. Secondly, raw rice kernels showed a characteristic cracking, opening up or corrosion of the kernels or profuse hairy growth from the surface at low to medium scores (i.e. at low to medium alkali concentrations) (BHATTACHARYA & SOWBHAGYA 1972b). Parboiled rice kernels, on the other hand, did not show the characteristic kernel cracking etc even in dilute alkali, but simply got swollen and gelatinized as a compact mass. Thirdly, the degraded parboiled kernels, unlike raw rice, showed little or a much narrower collar surrounding the central kernel mass.

However, as in raw rice (BHATTACHARYA & SOWBHAGYA 1972b), the degradation reaction with parboiled rice too in alkali in all cases got completed within 24 hr.

3.1.2. Effect of alkali concentration and of the degree of parboiling: Systematic studies were then carried

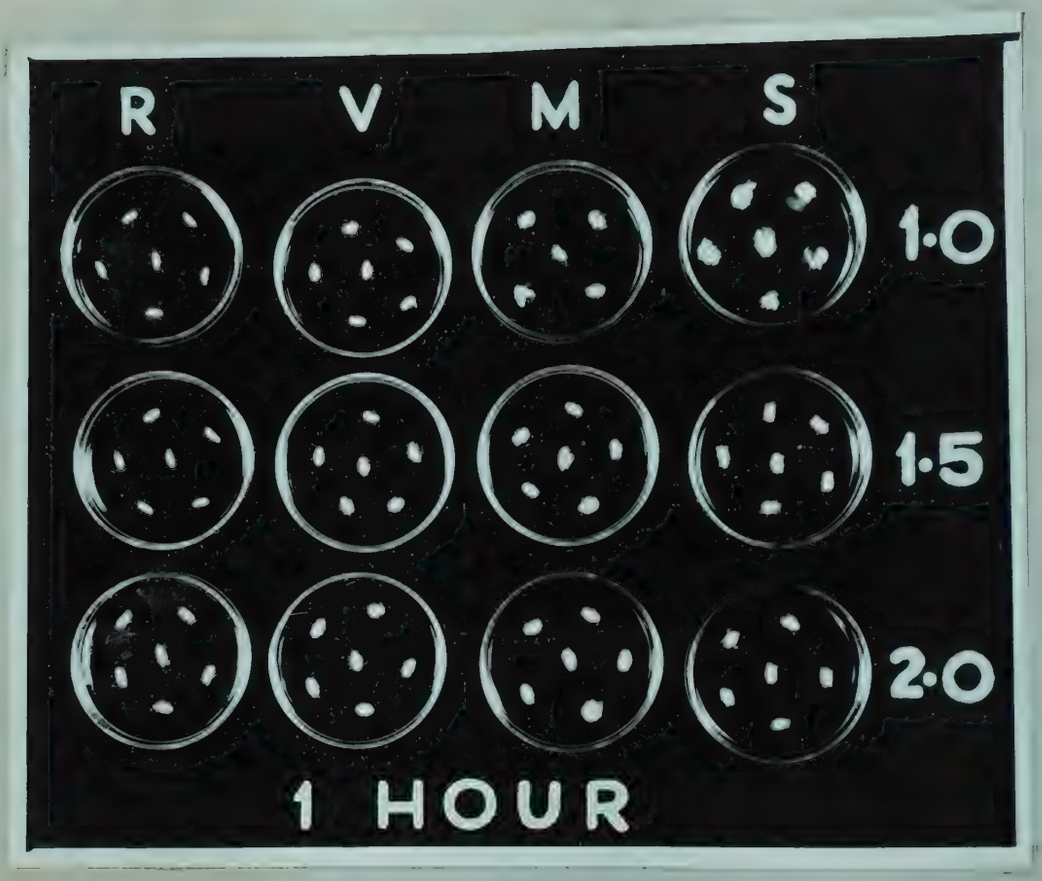
out with different alkali concentrations and with variously parboiled samples. The results obtained can be best illustrated by the following selected conditions.

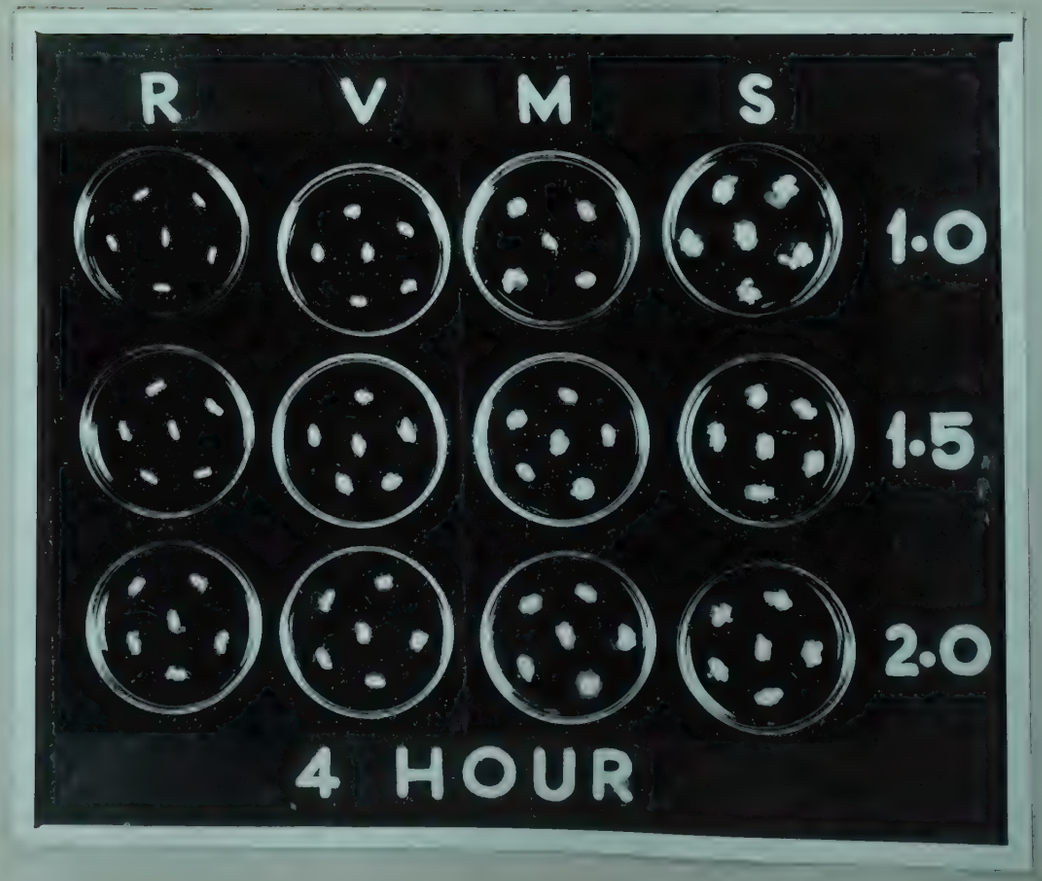
The alkali concentrations chosen (0.5, 1.0, 1.5, 2.0 and 5.0% KOH) are as follows: The middle concentration (1.5% - 'Moderate' alkali) was sufficient to give in raw Ratnachudi rice kernels a medium reaction score of 4-5; 1% ('Dilute') alkali was just below the KOH concentration needed for the raw kernels to give a barely perceptible reaction (i.e. a score of ½-1); and 2.0% ('Concentrated') alkali was just above a concentration needed for the raw kernels to be completely gelatinized (i.e., to give the highest score of 8). The remaining two concentrations on either extreme represented 'Very Dilute' (0.5%) and 'Very Concentrated' (5.0%) KOH respectively.

The samples included were: raw (R); and very mild (VM-PB), mild (M-PB) and severely parboiled (S-PB) (RT' soaked, steamed for 2, 10 and 60 min respectively) rice.

Fig. 11 shows some selected results, which can be summarised as follows:

(a) In Dilute alkali (1% KOH), the parboiled kernels gave a very rapid reaction, the extent of which increased with increasing severity of parboiling. The grains immediately developed a hairy film around them and bulged up slowly. The degraded kernels either did not develop any collar or showed a very thin and narrow collar with powdery deposition. The


R
V
M
S
1·0
1·5
2·0
1 HOUR


R
V
M
S
1·0
1·5
2·0
4 HOUR

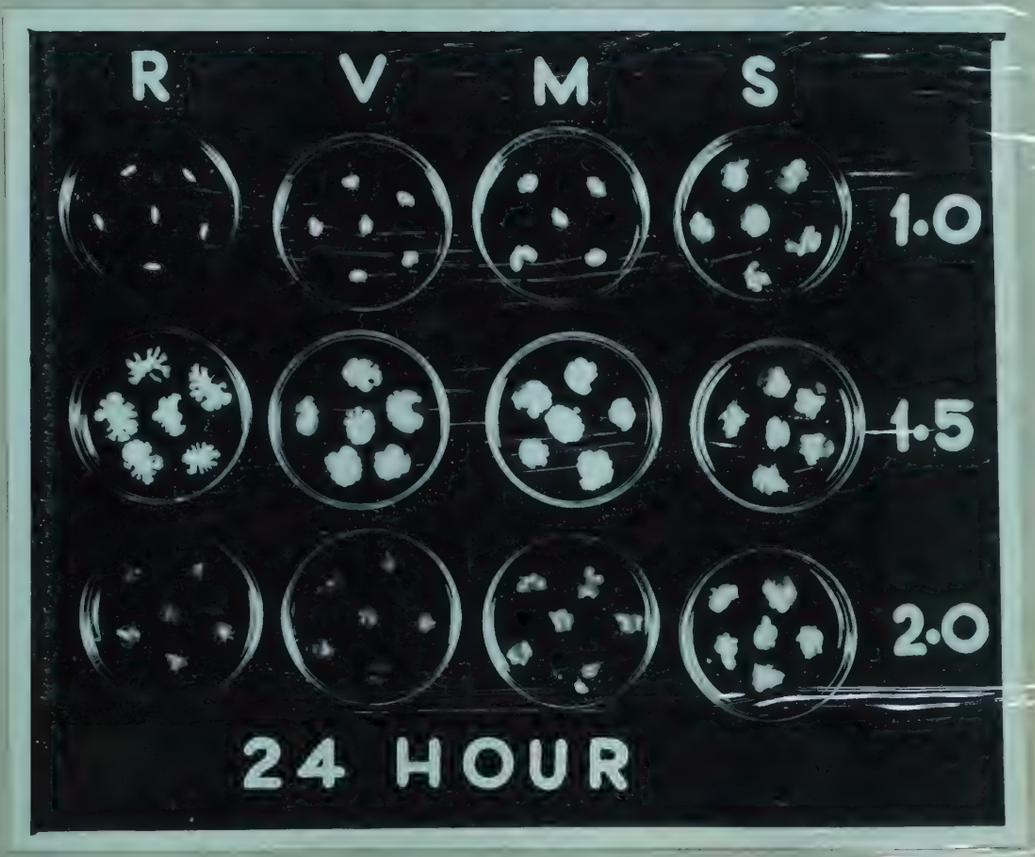


Fig. 11. Degradation of raw (R), and very mild (V), mild (M) and severely (S) parboiled rice kernels in 1.0 (Dilute), 1.5 (Moderate) and 2.0% (Concentrated) KOH after different time intervals.

kernels were not chalky (as in raw rice) but cottony in nature. The extent of reaction was lowest in VM-PB and highest in S-PB, where the kernels bulged up irregularly, lost their shape and became a fragmented swollen mass held loosely together. The raw rice kernels of course remained unaltered. Consequently within a matter of 1 hr or so, the observed reaction could easily distinguish between raw and parboiled rice and between parboiled rices of different severity. This initial reaction (1 hr) soon came to a stop and remained essentially the same even after 24 hr.

(b) In Moderate alkali (1.5%), the initial reaction (1 hr) in raw, VM-PB and M-PB were more or less similar as in Dilute alkali but that in S-PB was distinctly less. Further, degradation of all the samples, unlike in Dilute alkali, proceeded strongly with time but at a slightly inverse rate with the severity of parboiling. As a result, after 24 hr, R kernels gave the maximum reaction (typical of raw rice kernels -- score 4-5) and S-PB the least. Here again, the pattern of reaction of raw kernels was quite different from those of parboiled kernels, the difference increasing with increasing severity of parboiling: R was chalky, powdery and well spread out, while S-PB was highly swollen, gel type and compact with very little or no collar at all. On the whole there was a fair differentiation between raw and various parboiled kernels. The differentiation was however recognizable only after 24 hr, as compared to 1 hr or so in case of Dilute alkali.

(c) In concentrated (2%) alkali, the initial reaction (1 hr) was more or less same in all the rices. This initial reaction increased appreciably with time upto 24 hr, the relative extent again remaining more or less similar in all samples throughout. However, the final reaction pattern in S-PB and M-PB was appreciably different and in VM-PB slightly different from that in R; the degraded parboiled kernels were more compact and swollen and somewhat more opaque, with narrower collar, than the raw rice pattern. In the final reaction (24 hr) in this case too, raw, mild and severely parboiled rices could be differentiated, though rather poorly.

(d) In Very Dilute alkali (0.5% KOH, not shown), the extent of reaction and its pattern were similar to those in Dilute alkali (1% KOH) described above, although the reaction was slightly less and stopped a little earlier. Therefore, fairly good differentiation between raw and parboiled rice (of various degrees) could be made even with this concentration of alkali.

(e) The reaction in Very Concentrated alkali (5% KOH, not shown) proceeded rapidly with all rices without any distinction and increased with time, all the rices being equally and completely disintegrated after 24 hr.

3.2. Effect of Different Processing Conditions

It is clear from the above that the reaction in Dilute alkali (i.e. a KOH concentration just below the concentration

required to give a barely perceptible reaction in the raw rice of the same variety), viz. 1% KOH for Ratnachudi variety, could be used as a sensitive test of parboiled rice as well as of the degree of parboiling. Very dilute alkali could also be used, though with a slightly less sensitivity.

The effect of various processing conditions of parboiling was studied with the above test. Paddy soaked at 37°, 60° and 80°C for under-, optimum- and over-soaking periods followed by steaming at 0 psig for 10 min each were used. Rice milled in each case, both before and after steaming, were subjected to 1% KOH as above. Results indicated that rice milled from paddy which had been merely soaked at temperatures upto 60°C behaved just like raw rice (i.e. no reaction). But rice obtained from paddy merely soaked at 80°C behaved like parboiled rice, the extent of reaction increasing with the increased period of soaking. Rice from paddy soaked as above and then steamed (i.e. parboiled) showed the following pattern: Highest reaction was given by rices which were parboiled by optimal- or over-soaking at 80°C followed by that under-soaked at this temperature. Next came the rest of the parboiled rices (viz. soaked at 60° and 37° for different periods and steamed), all of which gave a nearly identical reaction. The extent and pattern of reaction showed by parboiled rices after soaking at 80°C (both optimal and over-soaked) was more or less similar to the S-PB as described above.

In other words, the alkali test too gave more or less an exactly identical result as the water-uptake and amylose-solubility tests.

Effect of mere soaking at 70° and of mere steaming: Rice obtained from Ratnachudi paddy which had been merely soaked at 70° for 1-6 hr (the last sample, after drying and milling, appearing as if fully parboiled), and also rice from paddy which was merely steamed for 15-30 min were also tested.

The reaction pattern in rice milled from all the 70°-soaked samples, however, remained equal to that of raw kernels (i.e. no reaction) except that the treated samples gave a very faint hairy collar when tested with 1.0% KOH. In 1.5% KOH, again, the reactions were nearly identical, except that the collar became very slightly narrower in samples with increasing time of soaking. Apparently the kernels, although appearing translucent, were either not gelatinized or were only very incipiently so.

Rice obtained from paddy which was merely steamed for 15-30 min again gave a reaction essentially similar to that of untreated raw rice, indicating that there was no gelatinization whatsoever in these samples.

3.3. Tests with Other Varieties

Similar tests with other varieties were then carried out to determine whether the above results were specific for

a given variety (Ratnachudi) or were of a general nature. Two more tall *indica*, 2 dwarf *indica*, 2 *japonica*, and 1 *indica* x *japonica* varieties were tested.

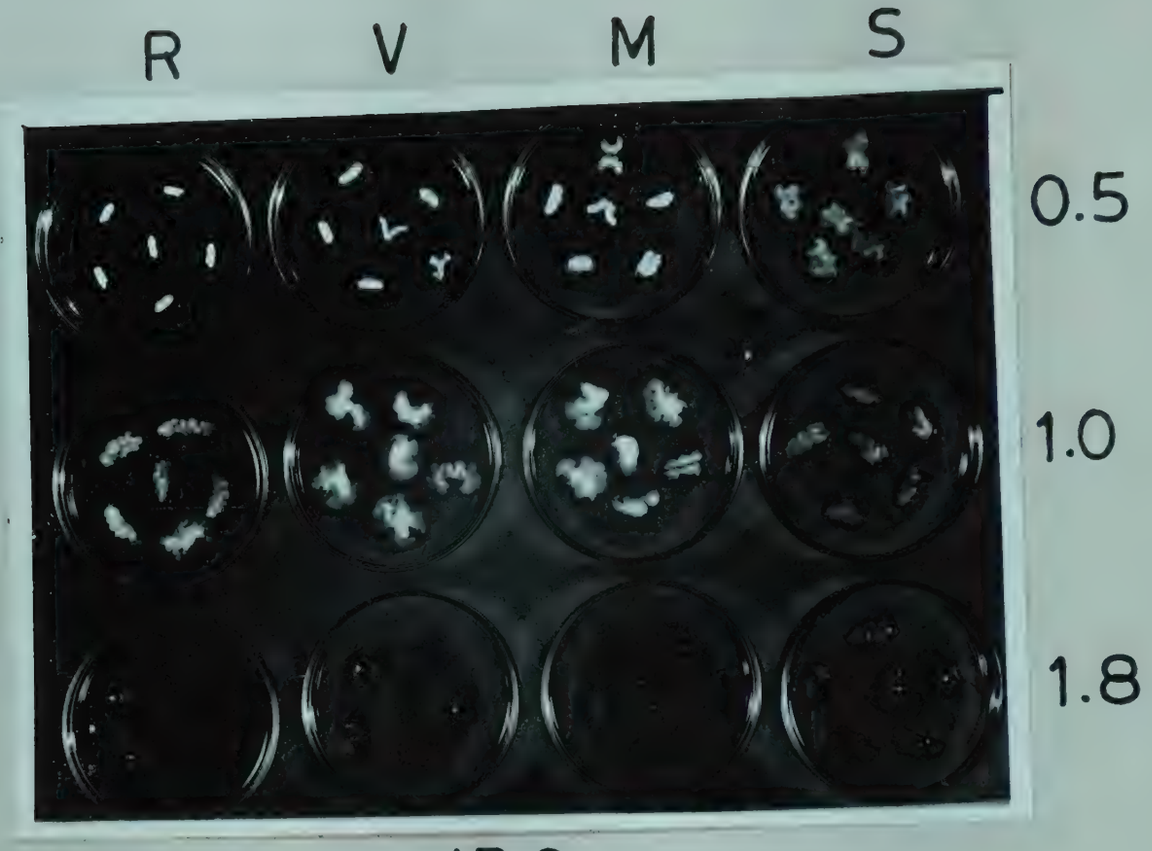
Raw rice as well as very mild, mild and severely parboiled rice (paddy soaked at RT' and steamed for 2, 10 and 60 min respectively) were prepared from each variety as before.

The raw kernels of the samples were first tested for their alkali reaction score in 1.4% KOH by the method of BHATTACHARYA & SOWBHAGYA (1972b). From the scores so obtained, the various alkali solutions (Very dilute, Dilute, Moderate, Concentrated and Very concentrated) for the corresponding varieties were calculated.

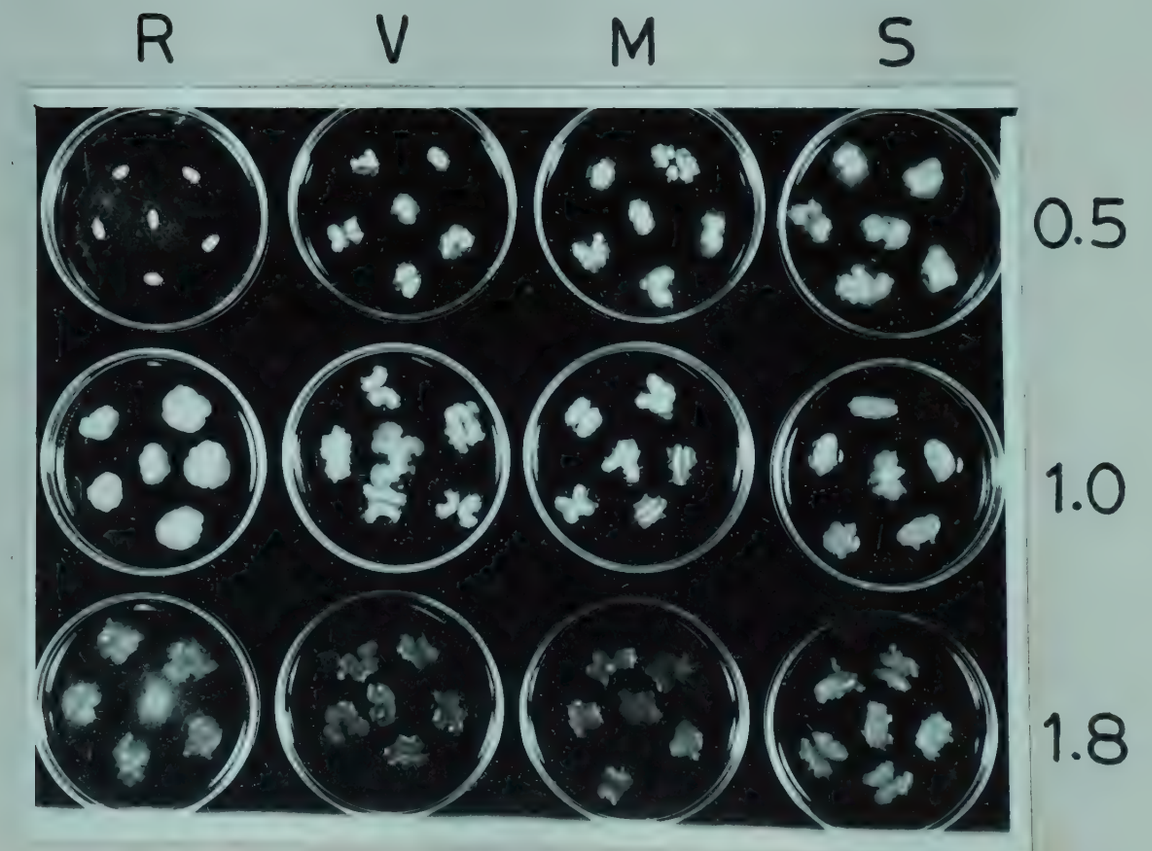
The pattern of the results obtained with the above were on the whole entirely similar to those obtained with Ratnachudi variety indicated earlier. A few selected results are shown in Fig. 12.

4.0. DISCUSSION

The results clearly indicate that reaction with Dilute or Very dilute alkali (i.e. KOH concentration of such strength that the corresponding raw kernels remain unreacted) can give an excellent test (and also a more or less instant test wherever that is important) to differentiate parboiled rice from raw rice and also parboiled rices of different severity. Such alkali did not attack raw rice kernels at all,



IR 8



Tn-3

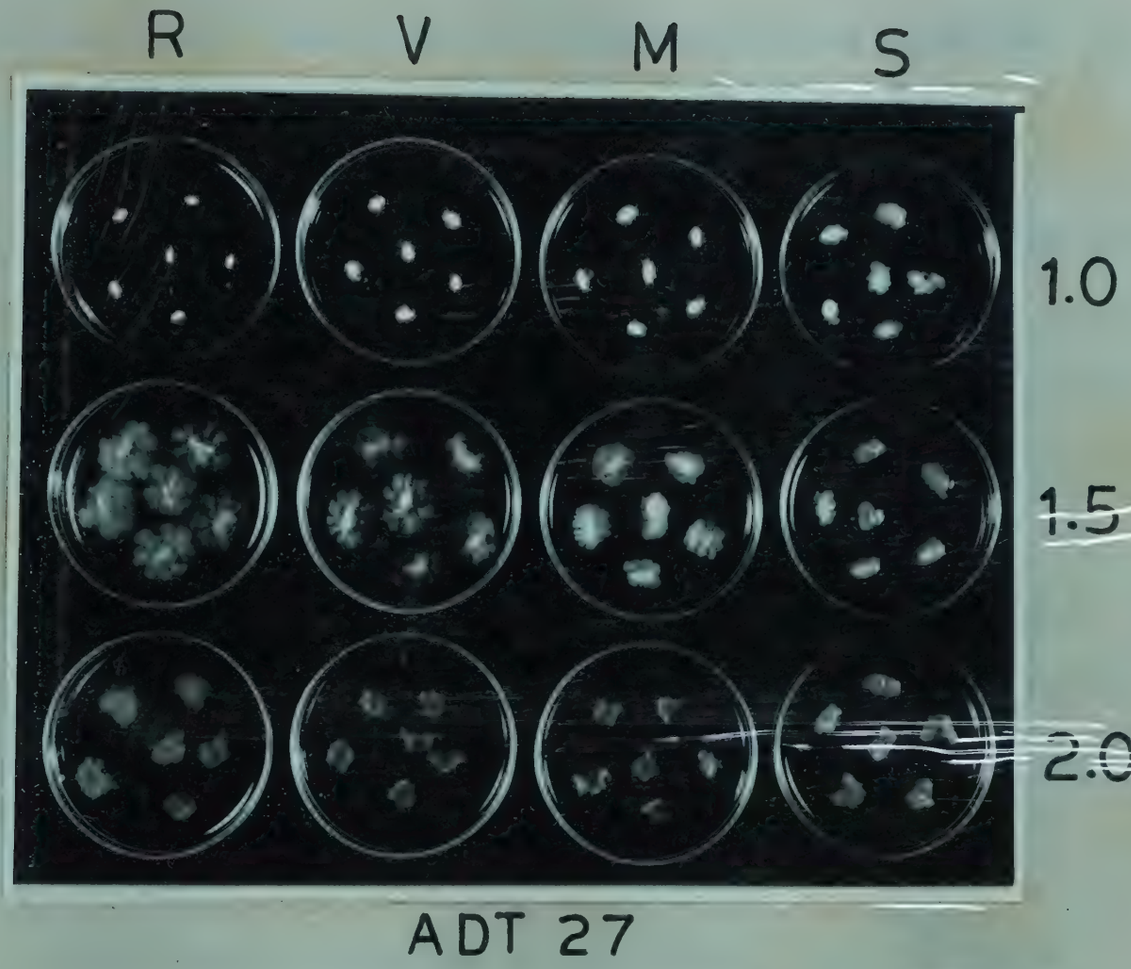


Fig. 12. Degradation of raw and parboiled rice of IR8, Tn-3 and ADT 27 varieties after 24 hr in alkali.

(Figures on right indicate KOH %)

but parboiled rice kernels got degraded proportionately to its degree of parboiling.

Apparently, the pregelatinization of parboiled rice makes it more susceptible to disintegration by dilute alkali than raw rice, severely parboiled kernels undergoing greater disintegration because of their more extensive gelatinization. This may also explain why the kernels did not undergo any cracking or corrosion, characteristic of the raw kernels. As the kernels were already gelatinized, there was nothing for them to be again newly gelatinized and so they merely swelled and hydrated in alkali.

The above behaviour of parboiled rice is quite similar to its hydration behaviour and also the amylose solubility at relatively low temperatures, where parboiled rice absorbs more water and gives out more amount of soluble amylose when compared to raw rice.

Regarding the reaction pattern of parboiled rice in Moderate and Concentrated alkali, which was apparently somewhat less in extent than in raw rice, it is possible that, as in the case of hydration and amylose solubility at high temperatures, retrogradation of the gelatinized starch in parboiled rice may have something to do with this phenomenon also. It could thus be seen that the behaviour pattern

of parboiled rice to alkali treatment too falls in line with the other properties studied (hydration and amylose solubility). This behaviour also, thus, lends further support to the hypothesis of a possible retrogradation or reassociation of starch following its gelatinization during heat treatment of parboiling process.

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Chapter VI

PASTING BEHAVIOUR OF PARBOILED RICE

1.0. INTRODUCTION

Determination of the pasting behaviour with a Brabender viscograph has long been a standard analytical tool in starch and cereal research and quality control. The technique is also now being routinely employed in rice quality research since its first use for this purpose by HALICK & KELLY (1959).

The pasting behaviour of parboiled rice, in contrast, has been studied only limitedly. RAGHAVENDRA RAO & JULIANO (1970) and ARAI et al (1975) observed that viscograms of parboiled rice were somewhat different from those of raw rice. The 'gelatinization temperature' -- i.e. the temperature of initial rise in viscosity -- was increased, while the other parameters -- viz. the peak viscosity, breakdown and setback -- were reduced. ARAI et al (1975) observed that these differences increased with increasing severity of parboiling. FERREL & PENCE (1964) had earlier noted that the magnitude of breakdown decreased with increasing degree of gelatinization in precooked rice; they in fact suggested this decrease as a test of the degree of gelatinization. PRIESTLEY (1976a) also

has recently determined the viscogram of parboiled rice with essentially similar results.

All the above studies were carried out with only one concentration of rice flour (8-11% slurry), as has usually been the practice in viscographic studies so far. MAZURS et al (1957), however, had suggested that a better idea of the pasting behaviour of a starch or flour is obtained by studying the change in viscogram pattern with changing slurry concentration. In fact, BHATTACHARYA & SOWBHAGYA (1978a) have recently shown that viscogram parameters determined at a fixed slurry concentration provide very little useful information.

The pasting behaviour of parboiled rice was therefore reinvestigated by using several slurry concentrations for each sample.

2.0. MATERIALS AND METHODS

2.1. Materials

Ratnachudi paddy was parboiled by RT' soaking and steaming for 2, 10 and 60 min at 0 psig to produce very mild (VM-PB), mild (M-PB), and severe (S-PB) parboiled rice. Rice was milled and ground (65-mesh flour) as already prescribed (Chapter II).

2.2. Viscography

Viscograms of the various samples were obtained with a Brabender viscograph using a 700 cmg sensitivity cartridge.

The method used was essentially that of HALICK & KELLY (1959). Several slurry concentrations in the range of 38 to 78 g flour (14% moisture, wet weight, basis) per 500 g total slurry (i.e. 7.6-15.6%) were used. The slurry was heated at the rate of 1.5°/min from 30°-95°C, held at that temperature for 20 min, and then cooled again at the rate of 1.5°/min down to 50°C.

The key viscosity indices (P, H, C : see below) obtained from the above viscograms were then plotted against the slurry concentration, both in semi-log and log-log coordinates.

2.2.1. Definitions: The following parameters are defined here for convenience.

'GT' = 'Gelatinization temperature' = Temperature of initial rise in viscosity.

P = Peak viscosity = Highest viscosity reached during heating, regardless of temperature. Where the viscosity did not show a clear peak but continued to rise till the end of heating, the H value was taken as the P value also.

H = Hot-paste viscosity = Viscosity attained at the end of heating for 20 min at 95°C.

C = Cold-paste viscosity = Viscosity attained at the end of cooling to 50°C.

BD = Breakdown = P - H

SB = Setback = C - P

SB_t = Total setback = C - H

$P^{max}_{BD=0}$ = Highest peak viscosity value given by a sample for which its breakdown is zero.

3.0. RESULTS

3.1. Effect of Slurry Concentration

Fig. 13 shows the complete set of viscograms of the different raw and parboiled rice samples drawn on rectangular coordinates. The various viscogram indices read from these curves are summarized in Table 11.

These data clearly bring out the similarities as well as the differences between the various samples. In each case, at a very low slurry concentration, the viscosity rose very slowly, with little or no peak, and there was no breakdown and only a small setback. This pattern changed with increasing slurry concentration, till at a very high concentration the viscogram showed rather a high peak, a relatively high breakdown and a high setback. The temperature corresponding to the peak viscosity also decreased progressively with increasing concentration. Further, the 'GT' continuously decreased as the concentration increased. These effects of slurry concentration on viscogram pattern have been noted by earlier workers also for various starches and flours (MAZURS et al 1957, SANDSTEDT & ABBOT 1964).

Although the above pattern was common to all the samples, the positions of the above changes and their

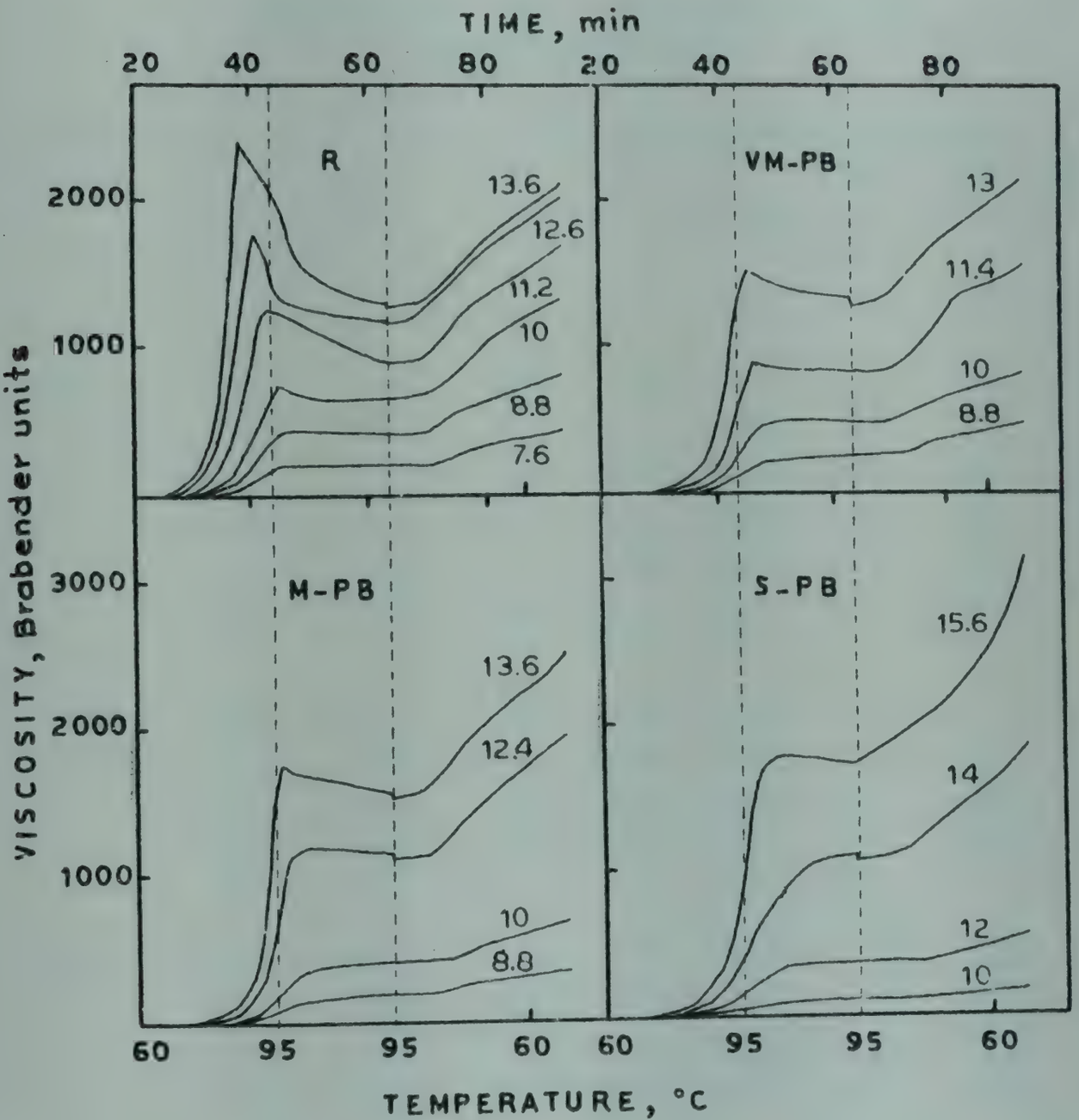


Fig. 13. Brabender viscograms of raw (R), very mild (VM-PB), mild (M-PB) and severely (S-PB) parboiled rice.

(The figures on curves indicate flour concentration in %, 14% moisture basis.)

Table 11

Viscographic characteristics of raw and parboiled rice

Sample	Slurry concentration (%)	'GT' (°C)	P	H	C	BD	SB	SB_t
			(B.U.)					
Raw	7.6	76	200	200	430	0	230	230
	8.8	72	435	415	790	20	355	375
	10.0	70.5	750	650	1310	100	565	665
	11.2	69	1265	900	1700	365	435	800
	12.6	69	1800	1190	2030	610	230	840
	13.6	69	2400	1290	2080	1210	-320	790
VM-PB	8.8	81	240	240	455	0	215	215
	10.0	75	475	475	800	0	325	325
	11.4	73.5	880	830	1560	50	680	730
	13.0	73	1550	1325	2140	225	590	815
M-PB	8.8	81	180	180	330	0	150	150
	10.0	76	400	400	660	0	260	260
	12.4	75	1180	1135	1940	45	760	805
	13.6	74	1750	1550	2500	200	750	950
S-PB	10.0	84	100	100	170	0	70	70
	12.0	79.5	375	375	540	0	165	165
	14.0	77	1080	1080	1890	0	810	810
	15.6	73.5	1780	1730	3150	50	1370	1420

magnitudes changed progressively from raw to VM-PB to M-PB to S-PB rice. For example, for any given slurry concentration, the 'GT' point rose, and the P, BD, SB and SB_t values

progressively decreased in the above order. The latter decrease was so great that the S-PB sample, for example, showed no breakdown even for the 14% slurry; and the peak was still flat even in the 15.6% slurry viscogram.

3.2. Comparison at Fixed P Values

The differences between the samples, other than those due to slurry concentration, are brought out better in Fig. 14, where the P, H and C values from the respective curves in Fig. 13 are plotted against the concentration in a semi-log plot as suggested by MAZURS et al (1957). By putting the concentration in the log scale, the effect of differences in concentration is eliminated and the various viscogram parameters can be judged more objectively.

It is clear that the P line was essentially similar in all the samples, except that the line was progressively shifted to the right (towards higher concentration) as the degree of parboiling increased. The H line as well as the C line, on the other hand, progressively rose from raw to VM-PB to M-PB to S-PB. As a result, for any given P value, the breakdown (P line - H line) progressively decreased, and the setback (C line - P line) seemed to increase with increasing degree of parboiling.

This is well brought out in Table 12, where the various viscogram parameters for the various samples at a peak viscosity value of 1000 B.U. are reproduced.

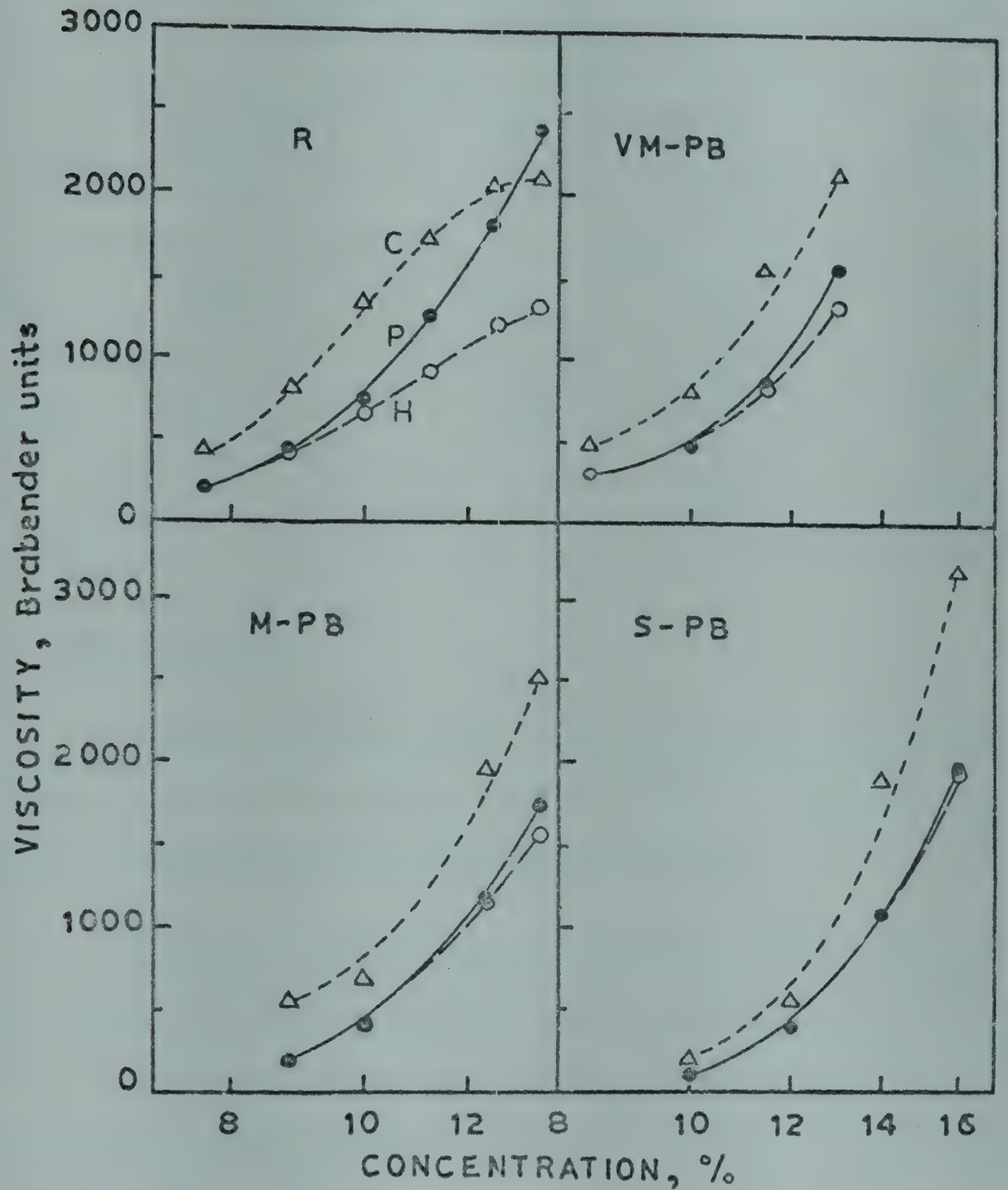


Fig. 14. Semi-log plots of Brabender paste viscosities of raw (R), very mild (VM-PB), mild (M-PB) and severely parboiled (S-PB) rice against slurry concentration.

(P, peak viscosity; H, hot-paste viscosity; C, cold-paste viscosity)

Table 12

Viscographic characteristics of raw and parboiled rice at a P value of 1000 B.U.

Sample	Slurry concn. (%)	BD	SB	SB_t
		(B.U.)		
Raw	10.8	160	500	660
VM-PB	11.7	80	660	740
M-PB	12.0	50	690	740
S-PB	14.4	0	800	800

3.3. Log-Log Plot

A still better idea of the differences among the samples is given by plotting the P, H and C viscosity values against concentration in log-log coordinates.

BHATTACHARYA & SOWBHAGYA (1978a, 1978b) have recently shown that very characteristic curves are obtained by plotting the P, H and C values against slurry concentration in log-log coordinates which, moreover, differentiates between different rice types (Fig. 15). In any rice sample, the C line crosses the P line at a particular point (the P.C intersection point) and the H line bifurcates from the P line at another point ($P^{max}_{BD=0}$). These two points, however, are characteristic of the rice quality type, as can be clearly seen in the figure. Thus the essential features of the curves remained identical for all the rice groups but the above two characteristic points

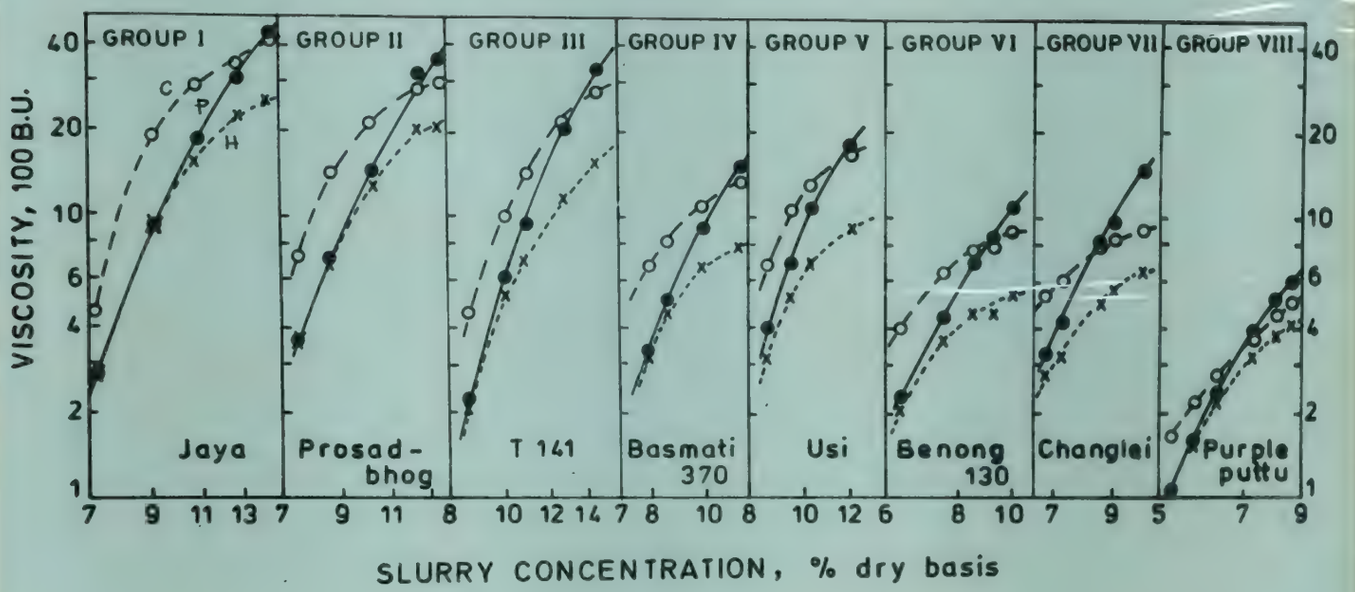


Fig. 15. Brabender viscograms of one representative rice variety (raw) each from eight groups. (P, peak; H, hot-paste; C, cold-paste viscosities)

(BHATTACHARYA & SOWBHAGYA 1978b)

shifted from group to group. These authors also suggested that viscograms for starches and flours could be better interpreted by comparing various viscosity ratios (H/P, C/P, C/H) and a new parameter called 'relative breakdown' (BD_r = breakdown/total setback = (P-H)/(C-H)).

The present data were therefore sought to be interpreted in the above manner. The log-log plot is shown in Fig. 16. This figure at once reveals that there was no essential difference between the various samples, except that the main effect of parboiling was only to push the curves towards a higher concentration side.

The C and H lines were parallel to each other in all the samples and their difference (in log scale) was also nearly the same in all. This indicated that the total setback ratio, C/H -- which is the true index of the increase in viscosity during cooling (rather than the arithmetic artefacts SB and SB_t, as in traditional practice) -- was nearly identical in all samples under all conditions. This is in accord with the findings of BHATTACHARYA & SOWBHAGYA (1978b) who observed this ratio to be nearly same for diverse rice varieties at diverse concentrations. The $P^{max}_{BD=0}$ point, however, was constantly pushed up as the sample was more and more severely parboiled. But since the C and H lines were more or less parallel, there was no doubt that once the H line diverted from the P line, the C line would also bend and eventually cross the P line at a later point. Only, this crossing point would be at such a

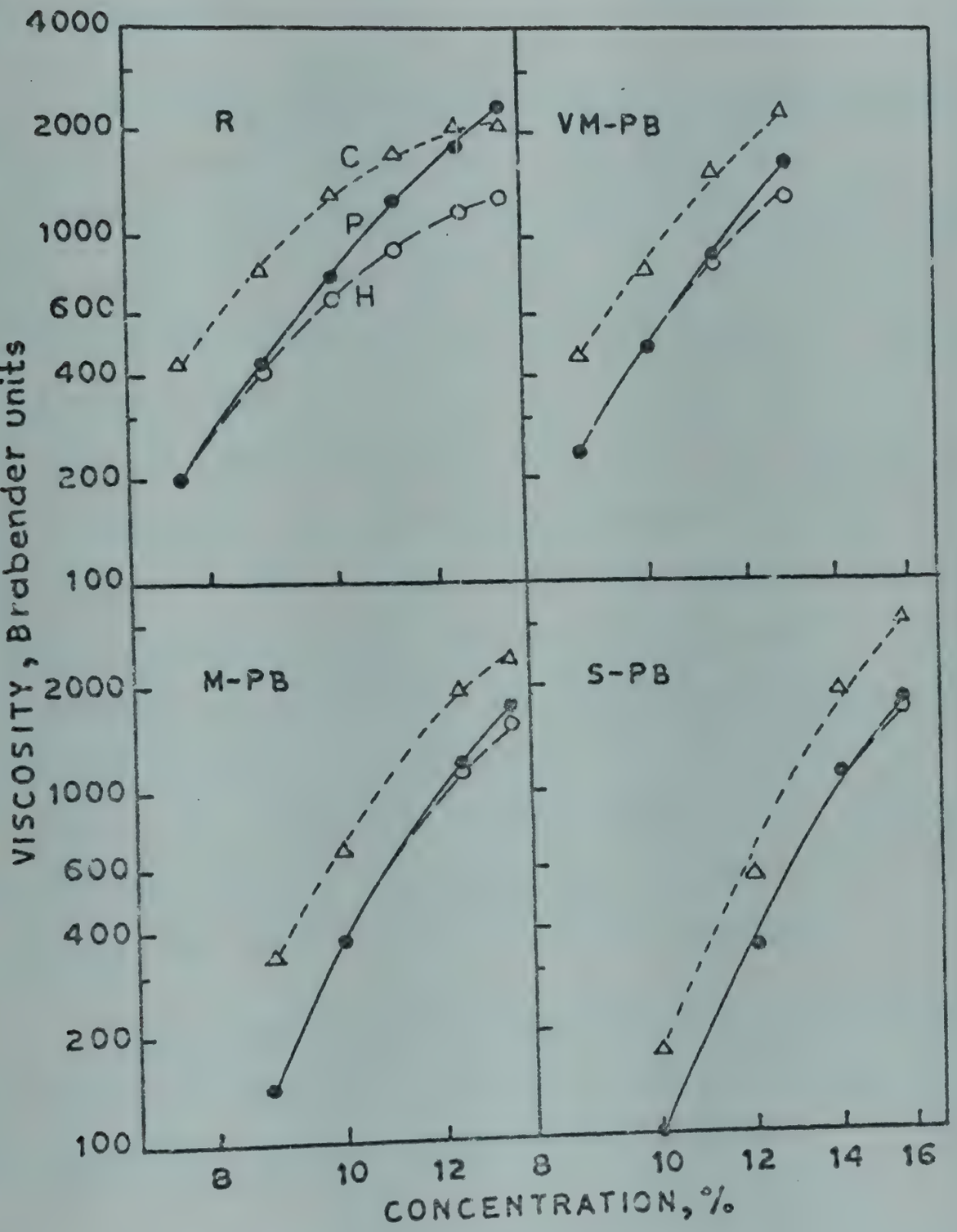


Fig. 16. Log-log plots of Brabender viscosities of raw and parboiled rice against slurry concentration.

high viscosity that it could perhaps not be registered in the present equipment.

The above analysis shows that the main difference between the various samples was in the $P^{max}_{BD=0}$ value, i.e. the peak viscosity value at which the sample first showed a measurable breakdown. Once this point appeared, the remaining portions of the curves were more or less identical. The parboiled samples thus fall in the same line of transition from group VIII to Group I rice (see Fig. 15). As a sample of rice is parboiled, its viscographic pattern is changed towards those characteristic of numerically lower groups (group VIII to VII to VI, etc.) and finally even beyond group I. This is also perfectly in accord with the observation that just as stickiness of cooked rice decreases and its consistency increases in the order group VIII to group I rice, parboiling also has the effect of decreasing the stickiness and increasing the consistency (and proportional to its severity).

The arithmetic parameters like breakdown, setback etc are nothing but artefacts and that is why they change arbitrarily and do not give much useful information.

4.0. DISCUSSION

The above results can be interpreted to mean that the main effect of parboiling on the pasting behaviour of rice is to reduce the extent of granule swelling.

When a starch slurry is heated in water, the granules gradually swell. When the swollen granules occupy a sufficient volume to offer some resistance to the rotating pins in the Viscograph bowl, a measurable viscosity is registered, which is the Brabender 'GT'. Again, as discussed by BHATTACHARYA & SOWBHAGYA (1978a), when the concentration of the slurry is such that the swollen granules do not occupy an appreciable fraction of the total available volume, they are not appreciably sheared by the rotating pins and hence continue to swell till the end of cooking. That is why a dilute slurry shows little or no breakdown. Conversely, at a high slurry concentration, the swollen granules occupy most of the available volume and are therefore severely sheared between the pins; hence they undergo extensive disintegration, i.e. the paste shows a high breakdown. If the rate of swelling of the granules is decreased, due to some reason, then the same phenomenon as above would be shown at a still higher concentration.

Since a rise in the 'GT' point and a decrease in the breakdown (at any given P value or at a given concentration) are precisely the two changes that are observed as a result of parboiling, it can be concluded that its main effect is to reduce the rate of granule swelling.

There may be two reasons why the rate of granule swelling is reduced by parboiling. One possibility is that the granules are more or less disrupted by gelatinization and

are therefore no longer in a position to swell as much as in the native state. The other possibility is that partial starch retrogradation following its gelatinization binds the granular structure together and inhibits its further swelling. Which is the precise reason, or whether it is due to both, cannot be said from the present data. Perhaps microscopic examination of the heated slurries at various stages may throw more light on the above.

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Chapter VII

COMPARATIVE PROPERTIES OF PARBOILED RICE AND FLAKED RICE

1.0. INTRODUCTION

Flaked rice (also called beaten rice or flattened rice) is a popular processed rice product widely produced as a cottage or small-scale industry in India. The process is essentially as follows (GHOSE et al 1960, NARAYANASWAMI 1956): Paddy is soaked in cold or warm water to hydrate and then drained. The soaked paddy is then manually roasted in hot sand in small (about 2 kg) lots with stirring in a shallow iron pan over a strong fire (usually a husk-fired open oven, called "Bhatti") for about a minute or less until the grain nears the puffing stage. After sieving out the sand, the paddy is flaked either by pounding in a wooden mortar and pestle, as in traditional practice, or by an power-driven edge-runner, as in current commercial establishments. The degree of flattening is adjusted as desired. The husk and a part of the bran, which are rendered quite brittle by roasting, get pulverised during flaking and are removed while the endosperm gets flattened.

It will be immediately observed that flaked rice is thus quite similar to parboiled rice, except that here the soaked paddy is gelatinized by roasting in sand instead of by being steamed (and that the gelatinized paddy is then further flaked). Yet, in striking contrast to parboiled rice, flaked rice has the unique property of becoming soft like cooked rice on simple standing in cold or warm water for a short period; parboiled rice on the other hand takes a longer time to cook than raw rice even in boiling water.

It was therefore considered worthwhile to study the hydration and other related properties of flaked rice at various stages of its production in comparison to those of normal steam-parboiled rice. It was hoped that this would throw some light on the differences between the two products and thereby provide a better understanding of the parboiling process also.

2.0. MATERIALS AND METHODS

2.1. The Flaking Process

Flaked rice was collected from a nearby commercial production unit (Shree Gajanana Oil and Rice Mills, Mysore, India). The process was as follows: Paddy (a local tall *indica*, SR 26 B variety) was soaked in warm water overnight and drained in the morning. About 2 kg lots were roasted in hot sand with constant stirring, for about 30-40 sec. The temperature of roasting was about 200°C. The final temperature attained by the paddy at the end of roasting was about

115°C. The roasted paddy was then flaked by an edge-runner to produce a thick (I) and a thin (II) grade of flaked rice. An idea of the change in dimensions of rice during flaking can be obtained from the following data:

Rice	Length	Breadth (mm)	Thickness
Milled raw rice	7.7	2.2	1.78
Flaked rice I	12.0	3.6	1.07
Flaked rice II	18.0	5.1	0.43

The moisture contents at the various stages were:

initial paddy	11.7%	moisture	(wet basis)
soaked paddy	29.4%	"	"
roasted paddy	17.0%	"	"
flaked rice I	16.7%	"	"
flaked rice II	14.5%	"	"
husk-bran mixture	6.7%	"	"

2.2. Materials

Samples were collected at various stages of processing as above: viz. original paddy, soaked paddy, roasted paddy, and flaked rice I & II. The paddy samples were shade dried in the laboratory and then milled as described (Chapter II). Rice milled from the roasted paddy will be referred to here as roasted-parboiled rice or simply roasted rice (RPB). It was found to contain about half the grains as fully translucent (just like normal parboiled rice) and the rest chalky (probably more dehydrated and hence severely fissured during roasting). These two types were manually separated and analysed separately for most of the parameters studied.

Parboiled rice of different severity was also prepared in the laboratory from the original raw paddy by RT' soaking and steaming for 2, 10 and 60 min at 0 psig to obtain very-mild (VM-PB), mild (M-PB) and severe (S-PB) parboiled rices respectively. The samples were shade dried and milled as usual.

2.3. General Methods

Equilibrium moisture content of whole grains on soaking in water at room temperature (EMC-S, % wet basis), and water uptake of rice at 60° (W_{60}) and 96°C (W_{96}) after cooking for 2 hr, were determined as described in Chapter III. Water-soluble amylose content of rice was determined at 50° and 96°C (sA_{50}, sA_{96}) after grinding in a Micro-Wiley Mill with 60-mesh screen as described in Chapter IV. The alkali reaction test was carried out as described in Chapter V by using 1.0% KOH solution.

The pasting behaviour of various samples was studied as detailed in the Chapter VI. A sample each of unmodified and pregelatinized (drum dried) tapioca starch, procured from Lakshmi Starch Factory Ltd., Kundara, Kerala (India) was also included for comparison.

2.4. Sedimentation Test

After a good deal of exploration (see later), the following method was adopted:

Finely ground flour (65 mesh, 2.00 g) is taken in a 25-ml glass-stoppered measuring cylinder (outside diameter, 22.0 mm; length of the graduation column, about 90 mm) and 20 ml of 0.05 N HCl is added with gentle shaking. The cylinder is stoppered and the slurry mixed by repeated inversion. A drop or two of amyl alcohol is added on top to disperse the froth and the cylinder is left undisturbed. The sediment volume is read off after standing for 4 hr.

3.0. RESULTS

3.1. Hydration Properties

Equilibrium moisture content attained by rice on soaking in water at room temperature (EMC-S) of parboiled rice was in the familiar range (Table 13). In striking contrast, the EMC-S of flaked rice was extremely high (80% or more, w.b.). This immediately explains why it can be "cooked" even at room temperature; fully cooked rice contains no more than 75% moisture (BHATTACHARYA & SOWBHAGYA 1971). Interestingly, the roasted rice too had very high EMC-S value (62-67%, w.b.), far higher than even the severely parboiled sample. In fact, the true measure of differences among the samples is given by the moisture contents on dry basis: The roasted and flaked rices showed nearly double and 4-6 times the moisture-absorption power as compared to S-PB, respectively. The results suggested as if R-PB was more severely parboiled than even S-PB and flaked rice was still more severely parboiled.

Table 13

Hydration characteristics of raw, parboiled, roasted and flaked rice

Rice	EMC-S (%) w.b.	EMC-S (%) d.b.	W_{60} (g/g rice)	W_{96} (g/g rice)	W_{60} / W_{96} (%)
Raw	26.8	40	0.22	5.03	4.4
Parboiled:					
VM-PB	35.0	54	0.45	4.33	10.4
M-PB	36.7	58	0.51	4.01	12.7
S-PB	47.2	90	1.74	3.69	47.1
Roasted:					
Translucent	62.2	164	1.62	4.10	39.5
Chalky	67.3	206	1.96	4.48	43.7
Flaked:					
Thick(I)	79.2	380	3.42	6.51	52.4
Thin(II)	84.9	562	5.04	7.72	65.2

Coming to the water uptake values, the roasted rice showed a more or less similar W_{60} value as the S-PB sample, but its W_{96} was distinctly higher than S-PB and was closer to that of the VM-PB. In other words, it behaved <u>like</u> S-PB in the W_{60} and the W_{60}/W_{96} tests, but as <u>less</u> severely parboiled than S-PB (i.e. like VM-PB or M-PB) in the W_{96} test. Among the two samples of the roasted rice studied, the results were slightly

more exaggerated in the chalky kernels than in the translucent kernels. Flaked rice too showed more or less similar trends but the results were very much more exaggerated here. Its very high water uptake values at 60° and 96°C were, however, partly due to its high surface area.

3.2. Soluble Amylose Content

The pattern of results of the soluble-amylose content of various products, both at a low (50°) and at a high temperature (96°C) of extraction, and their ratio (Table 14), was generally similar to the hydration results. The sA_{50} value, as expected, increased with increasing severity of parboiling. On the other hand, the total soluble amylose content (sA_{96}), again as expected, decreased steadily from raw rice to S-PB. Roasted as well as flaked rices gave more or less the same sA_{96} value as the S-PB, but they showed a very high sA_{50} value. In other words, they behaved like S-PB in the sA_{96} test but as more severely parboiled rice in the sA_{50} test. Their soluble-amylose ratio (sA_{50}/sA_{96}) was also extremely high.

3.3. Alkali Degradation Test

The roasted and the flaked rice kernels gave a very quick response to the alkali degradation test (Fig. 17). They were degraded rapidly and to a greater extent than even the S-PB sample. This indicated as if they were still more severely parboiled than even the S-PB sample.

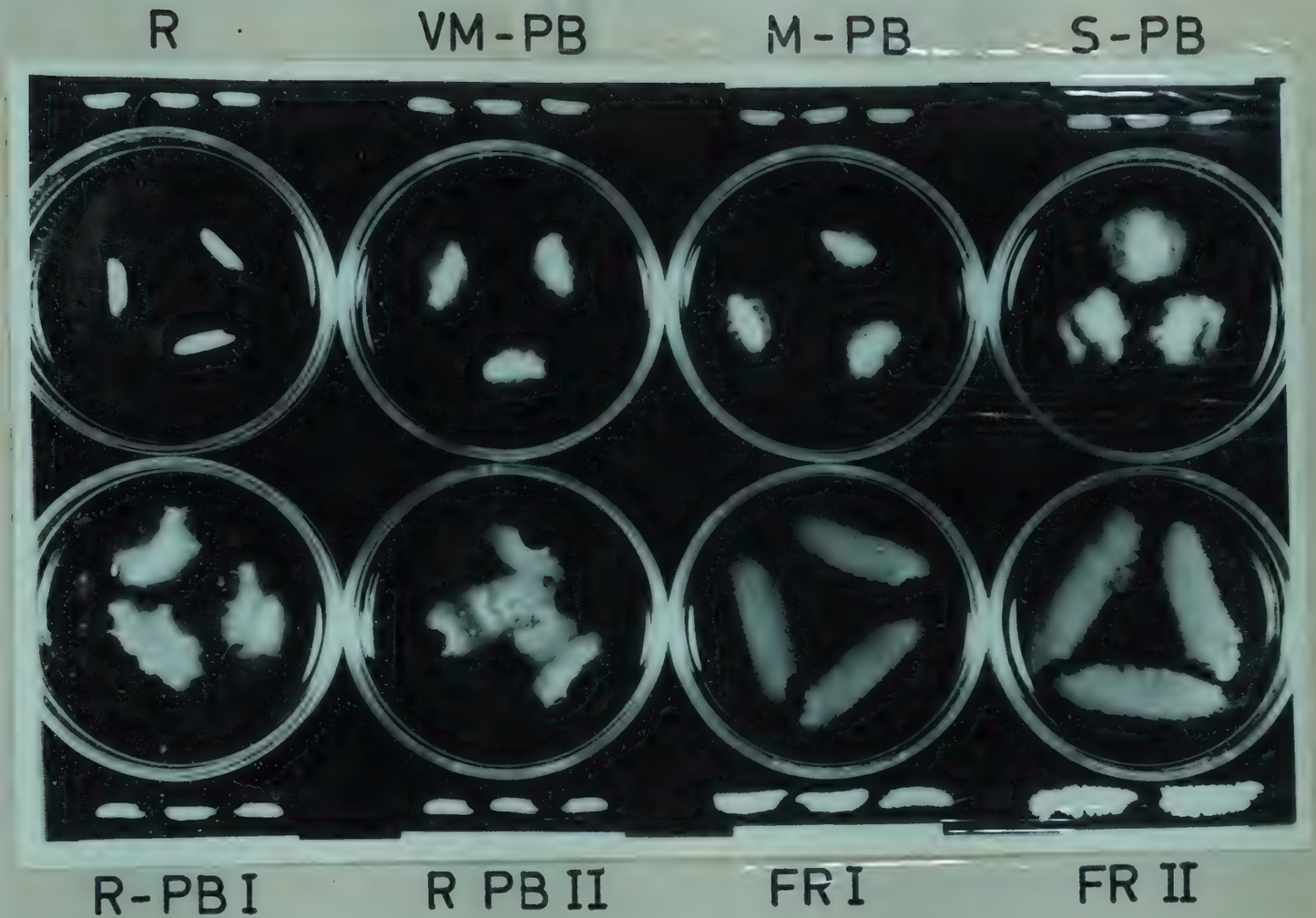


Fig. 17. Alkali degradation test of raw rice (R); very mild (VM-PB), mild (M-PB) and severe (S-PB) parboiled rice; roasted-parboiled rice: translucent (R-PB I) and chalky (R-PB II); and flaked rice: thick (FR I) and thin (FR II) in 1.0% KOH.

(Untreated kernels are shown alongside.)

Table 14

Amylose solubility of raw, parboiled, roasted and flaked rice

Rice	sA_{50} (% dry basis)	sA_{96} (% dry basis)	sA_{50} / sA_{96} (%)
Raw	0.18	14.0	1.3
Parboiled:			
VM-PB	0.23	13.9	1.7
M-PB	0.36	13.6	2.7
S-PB	0.54	8.6	6.3
Roasted:			
Translucent	3.02	7.9	38.2
Chalky	3.89	8.6	45.2
Flaked:			
Thick (I)	3.30	8.7	38.0
Thin (II)	5.02	10.5	47.8

3.4. Pasting Behaviour

The viscographic parameters (Fig. 18), drawn in log-log plot, showed a characteristic shift in the pattern from raw rice to mild to severe parboiled rice, as already observed in the case of RC variety (Chapter VI). The curves for roasted parboiled rice were somewhat different from those of the other samples, in that the curves bent upwards; the reason for this difference is not immediately evident. However, barring this

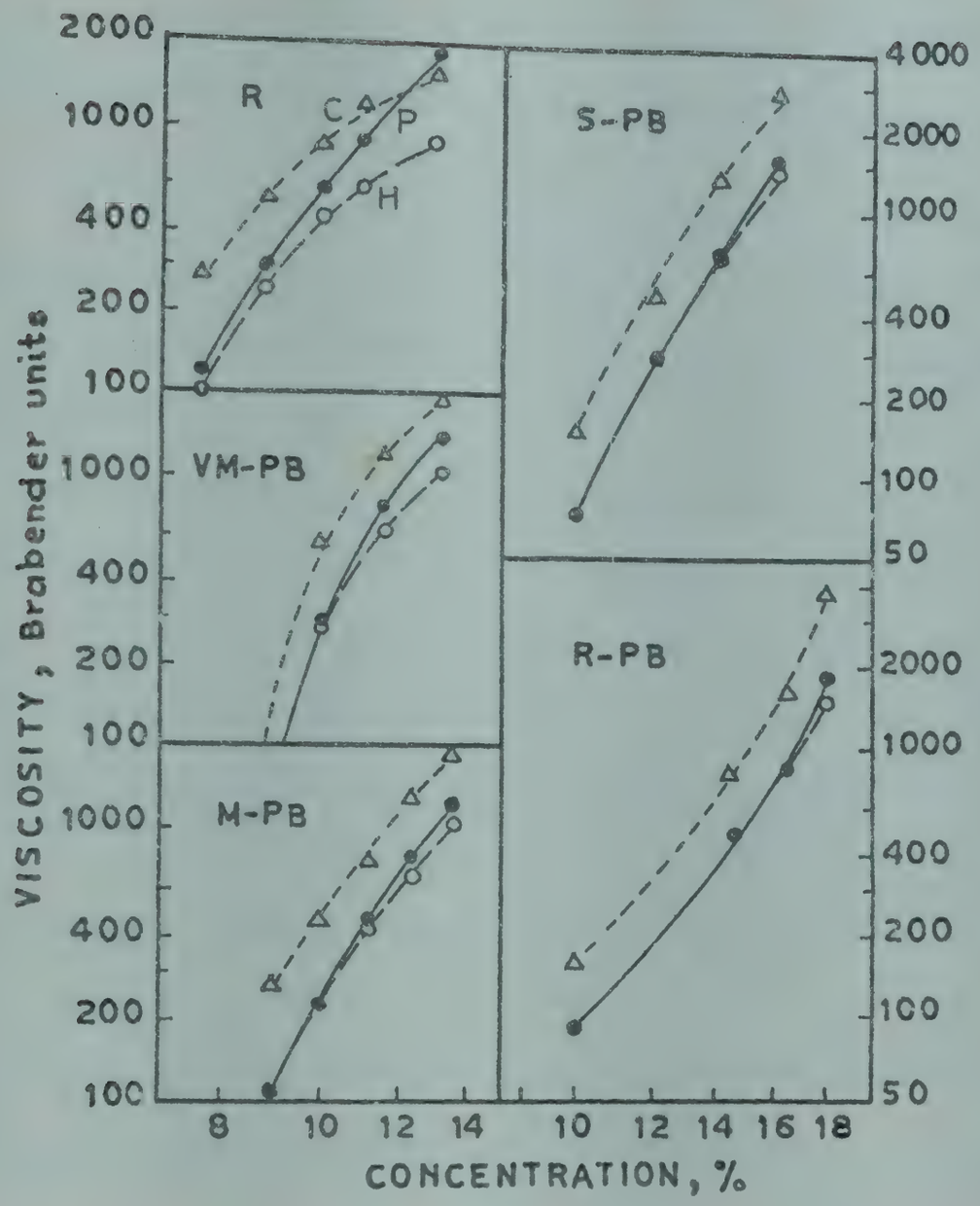


Fig. 18. Log-log plots of Brabender paste viscosities of raw (R), very mild (VM-PB), mild (M-PB), severe (S-PB) parboiled and roasted (R-PB) rice against slurry concentration.

(P, peak; H, hot-paste; C, cold-paste viscosity)

difference, their overall pattern fitted in a general way the shift from R to VM-PB ..... to S-PB rice, suggesting as if it was more severely parboiled than the S-PB rice.

But there was a marked difference between the various parboiled rices on the one hand and the roasted and flaked rice on the other, which could be seen when examining the full viscograms (Fig. 19). This difference lay in an unusual initial viscosity which the roasted rice slurry showed even before being heated in the viscograph. When it came to flaked rice, the pattern was distinctly different and the initial viscosity was still more pronounced. Careful observations showed that the parboiled rice samples too showed an initial viscosity but of an extremely small extent. Unmodified as well as pregelatinized tapioca starch were also studied for comparison. Significantly, the pregelatinized tapioca starch too gave a very high initial viscosity, and its viscogram was similar in essential features to that of flaked rice.

3.5. Sedimentation Volume

As mentioned above, the roasted and flaked rice flours developed a measurable viscosity even at room temperature when mixed with water during the preparation of the slurry for viscograph studies, demonstrating a distinct cold-swelling behaviour. It was also noticed that the slurry did not show much tendency to settle. Parboiled and raw rice flours, on the other hand,

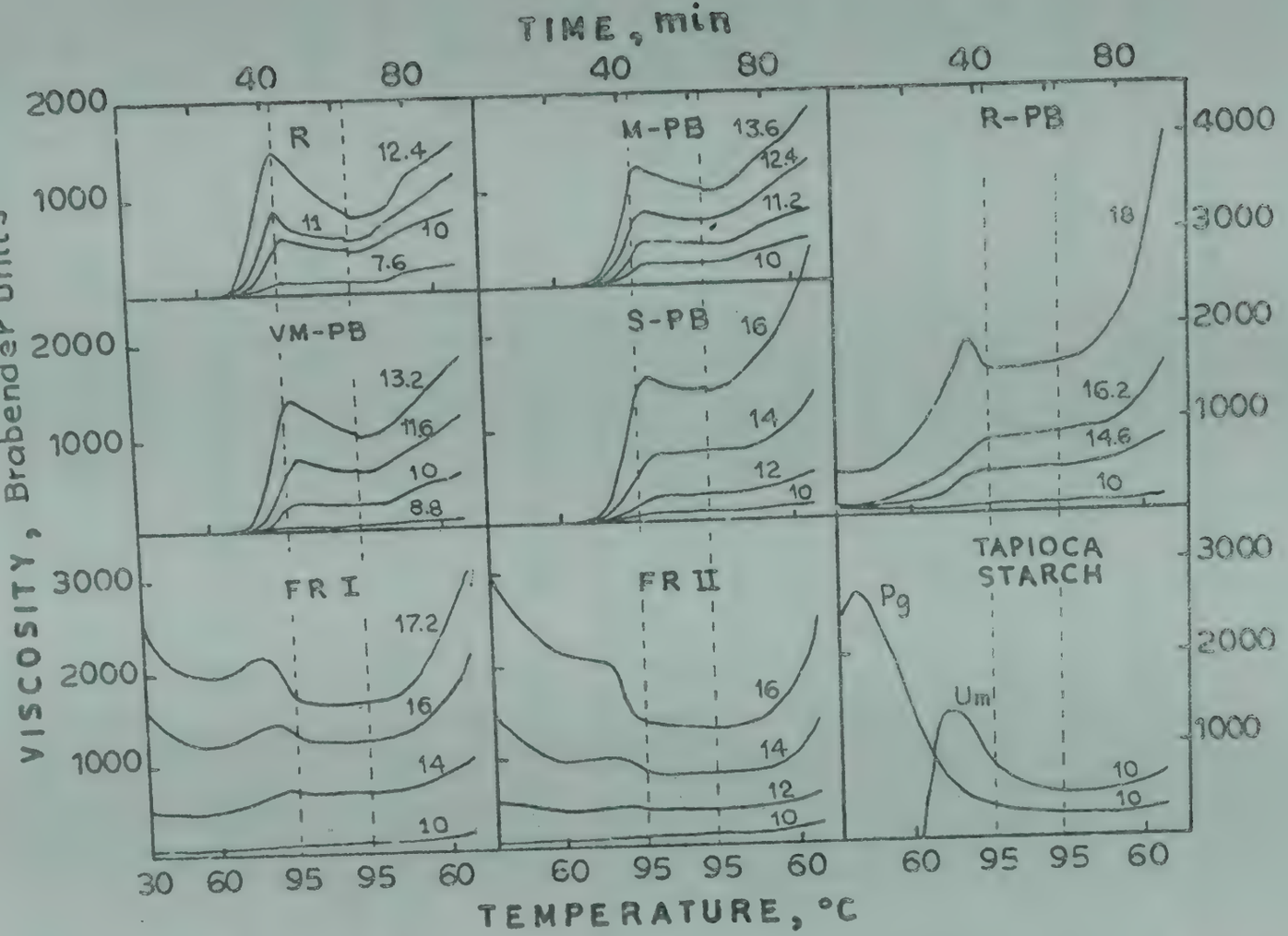


Fig. 19. Brabender viscograms of raw, parboiled, roasted and flaked rices and unmodified (Um) and pregelatinized (Pg) tapioca starch.

(The figures on curves indicate flour concentration in %, 14% moisture basis.)

gave little or no viscosity in cold water and their particles settled quickly in it. These differences suggested a new sedimentation test for these products.

Simple water slurry was found to give a rather turbid supernatant; it was largely clarified when the water was made slightly acidic. The pH of the dispersing medium influenced the sediment volume somewhat and hence 0.05 N HCl was selected. Dilute acetic acid (1%), lactic acid (7%), and isopropanol (10%, all v/v), were also tested but gave no additional advantage. Particle size of the flour affected the sediment volume slightly (finer flour giving higher volume). Hence the flour used for viscographic studies (approximately 65 mesh) was employed. A proportion of 2 g flour to 20 ml of the liquid gave convenient results. The sediment volume changed slightly with time but became practically constant after about 4 hr. Based on the above findings, a sedimentation test as described under Materials & Methods (section 2.4.) was devised.

The sediment volumes of the various samples are given in Fig. 20. Parboiled rice gave a small but distinctly greater sediment volume compared to raw rice, increasing with the increasing severity of parboiling. Roasted rice gave a much higher volume and flaked rice still higher. Unmodified and pregelatinized tapioca starch were also tested for comparison; the pregelatinized sample gave a fully dispersed translucent and viscous slurry with no tendency to settle.

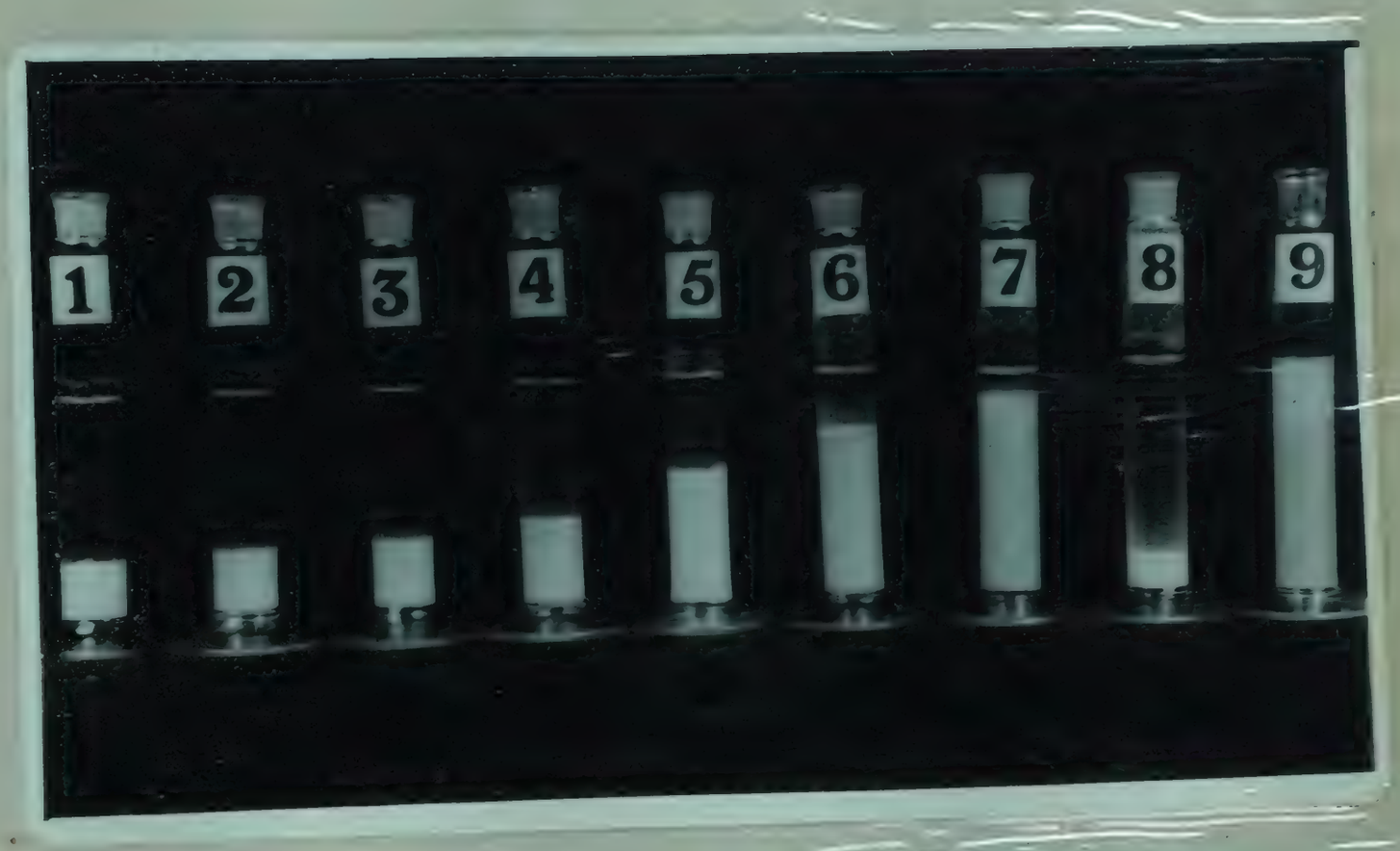


Fig. 20. Sediment volume of various rice products.

1 Raw rice -- 5.5 ml
2 Very-mild parboiled rice -- 6.2 ml
3 Mild parboiled rice -- 6.7 ml
4 Severely parboiled rice -- 8.1 ml
5 Roasted parboiled rice -- 12.8 ml
6 Flaked rice (thick) -- 16.2 ml
7 Flaked rice (thin) -- 19.5 ml
8 Unmodified tapioca starch -- 3.6 ml
9 Pregelatinized tapioca starch -- 22.5 ml

This simple test thus probably could be used as a useful test for precooked cereal products. When the pregelatinized tapioca starch was used in the proportion of 0.5 g to 20 ml (instead of 2.0 g to 20 ml), it gave a sediment volume of 15.2 ml. Hence by adjusting the solvent-to-powder proportion, the use of the test can probably be extended to other pregelatinized starch products as well.

A comparison of the sediment volumes with the EMC-S values of the products showed that the two parameters were correlated (Fig. 21). Similarly the initial viscosity of the unheated slurry of the products in the Brabender viscograph too was correlated with the sediment volume (Fig. 22).

Clearly it is the high degree of hydration which caused the viscosity, which in turn prevented the particles from settling (high sediment volume).

4.0. DISCUSSION

The above results show that the roasted rice behaved in a somewhat anomalous way in comparison to parboiled rice. It behaved as if it were a very severely parboiled rice in many of its properties (EMC-S, sA_{50}, sA_{50}/sA_{96}, alkali reaction), rather like severe parboiled rice in certain other properties (W_{60}, W_{60}/W_{96}), but like very mild parboiled rice in its W_{96} value. In other words, while in many respects it behaved like severe or extremely severe parboiled rice, it did not show

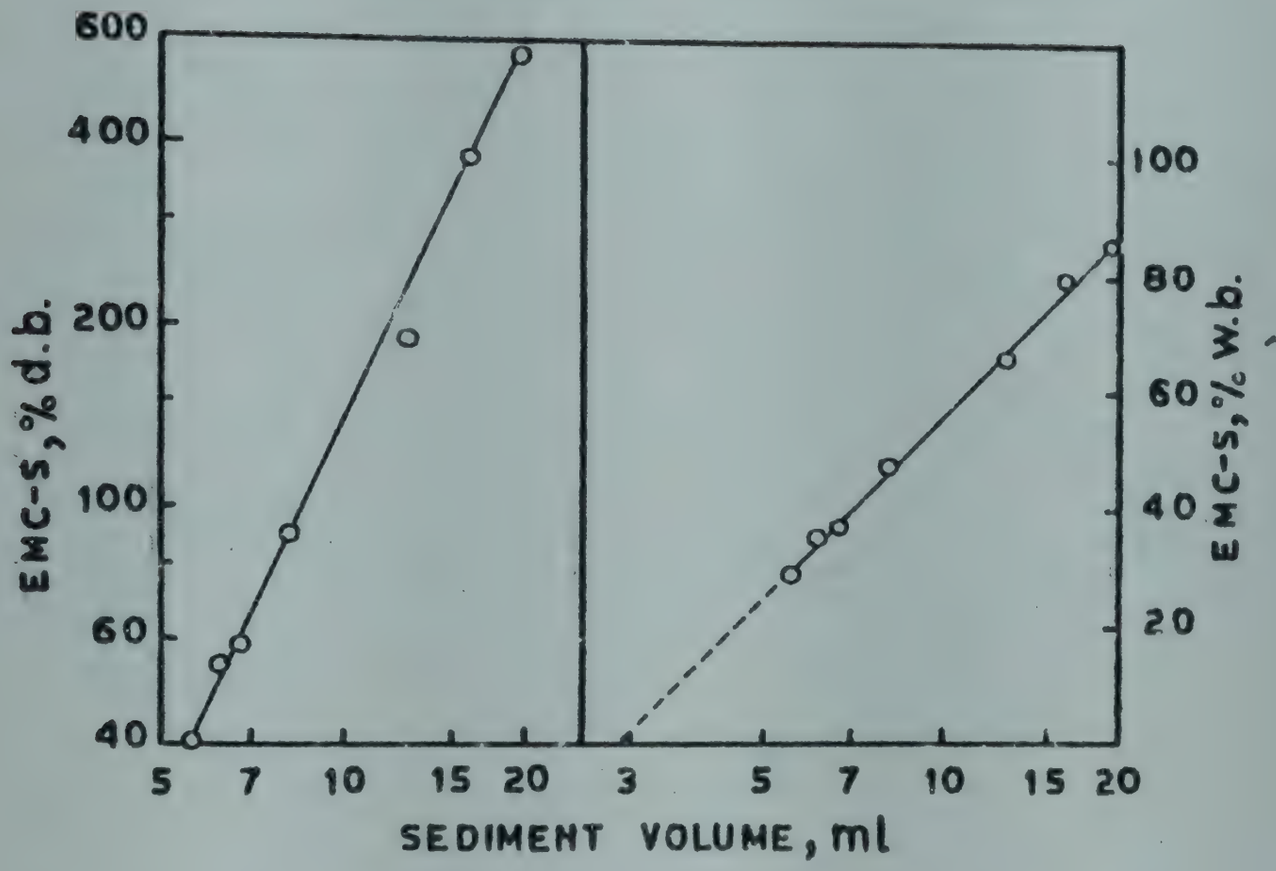


Fig. 21. Relationship between sediment volume of various products and equilibrium moisture contents attained by them on soaking in water at room temperature.

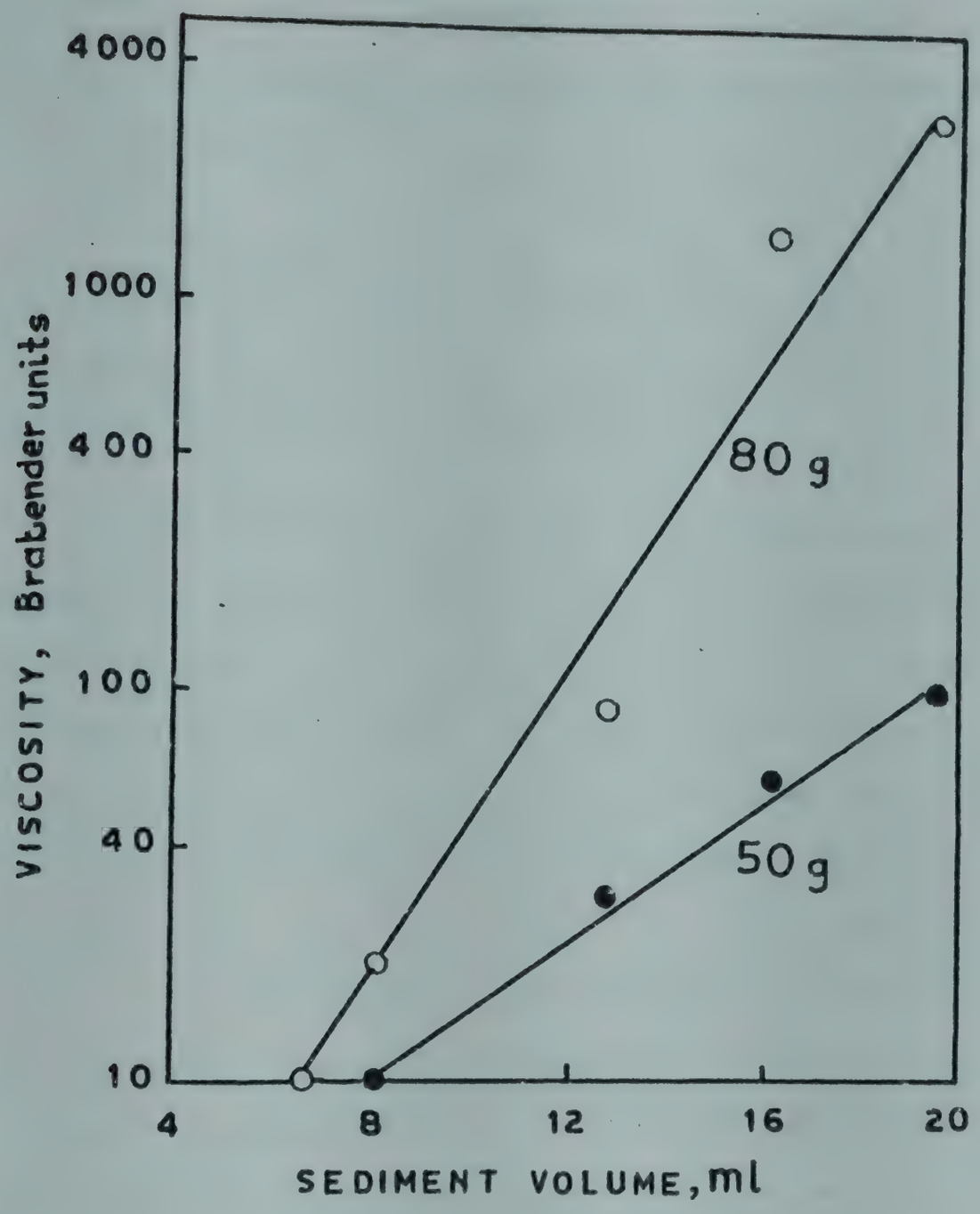


Fig. 22. Relationship between sediment volume of various rice products and their initial viscosity of the slurry in the Brabender viscograph (30°C).

a corresponding lowering of the 96° hydration power characteristic of such severely processed rice. Besides, it showed a distinct cold-swelling behaviour (viscosity and sediment volume of a cold slurry) not shown by even severely parboiled rice.

While some of the above results are not yet quite clear (e.g. the rather anomalous amylose solubility behaviour), they are broadly consistent with the theory of partial starch retrogradation following its gelatinization.

It would seem that gelatinized starch has an inherent tendency to retrograde under favourable circumstances. However, rapid dehydration during or immediately following gelatinization would seem to prevent or reduce this retrogradation. Thus pregelatinized starch produced by drum drying of a starch slurry is known to show more cold-swelling property when it is dried in a thin layer than when it is in a thick layer (POWELL 1967). In a like manner, the rapid and simultaneous dehydration occurring during gelatinization in the production of roasted rice would seem to reduce starch retrogradation in it. The relatively high viscosity and sediment volume of a cold slurry of roasted rice, and its essential similarity to pregelatinized tapioca starch in these respects, are consistent with the above hypothesis. This would also explain why, unlike in normal parboiled rice, the 96° water-uptake value is not appreciably reduced in roasted rice (in comparison to raw rice) although all other properties suggest a high degree of gelatinization in it.

The contrasting behaviour of parboiled rice as compared to roasted rice, especially its low cold-swelling property and its reduced 96° hydration, would strongly suggest, in contrast, that a part of its gelatinized starch is retrograded during its slow drying following gelatinization. The other hydration (EMC-S, W_{60}) and alkali-reaction behaviours of parboiled and roasted rice are probably a net reflection of these two contrary phenomena (gelatinization and retrogradation).

The above reasonings, however, cannot fully explain the properties of flaked rice. If prevention of retrogradation (because of quick drying during roasting) was alone involved, the properties of roasted and flaked rice should have been identical (except that flaked rice would hydrate faster, but not necessarily to a greater extent, due to its greater surface area). But this clearly is not the case. All tests (except sA_{96}) showed a marked difference between the two products, increasing with the increasing degree of flaking. In particular, flaked rice showed a much greater EMC-S and cold-swelling behaviour than roasted rice. Clearly, some additional changes are occurring during the flaking step. The differences could be due to further prevention of retrogradation because of additional drying during the process of flaking. Alternatively, it could be due to mechanical damage of the cell or tissue structure during flaking, or due to some other unknown reasons.

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Chapter VIII

RETROGRADATION OF STARCH IN PARBOILED RICE

1.0. INTRODUCTION

Work reported in the earlier chapters, particularly in the last one, gave strong indications that starch in normal parboiled rice was partially reassociated or retrograded. Attempts were therefore made to confirm it by a direct study of starch retrogradation. The stage of onset of the reassociation phenomenon and its progress and dependence on various factors were also thought to be studied.

2.0. MATERIALS AND METHODS

2.1. Materials

Ratnachudi paddy, obtained from a nearby Agricultural Research Station, was used. It was one year old after harvest when the studies were initiated. The paddy was parboiled (RT' soaking and steaming at 0 psig) and milled as described (Chapter II). Severely parboiled rice (60 min steamed) was usually used so as to magnify the results.

2.2. Holding

For study of retrogradation, samples were often held either at room temperature (RT = 25-32°), for 24 hr (when time is not specified), or at higher temperatures before

testing. For this, the rice or paddy was put in a test tube, full to the brim, and closed tightly with a rubber cork. For storing at higher temperatures, the test tube was put in an oven maintained at the desired temperature +2°C; the cork was momentarily opened after several minutes to release the internal pressure.

2.3. EMC-S

The equilibrium moisture content attained by rice on soaking in water at RT for 24 hr was determined as described (Chapter III). Since changes in the EMC-S value in the same product as a result of storage etc are considered here, the EMC-S values are presented here on dry weight basis to bring out the changes in moisture-imbibing capacity better. The moisture content of the product under study, however, is reported on wet basis as usual.

For studying the onset and progress of retrogradation in parboiled paddy after its steaming, the EMC-S had to be determined immediately; otherwise too, sometimes it had to be determined in the stored wet paddy without drying. Since such wet paddy could not be milled, the EMC-S had to be determined in the paddy itself. Preliminary studies showed (Table on page 112) that, in severely parboiled paddy, neither the paddy nor its brown rice gave the true EMC-S value as given by the corresponding milled rice. However, when the brown rice was cut open to expose the endosperm, it gave the true value.

Sample [a]	Moisture content (%, w.b.) attained after soaking in water for		
	24 hr	48 hr	72 hr
Paddy	41.0	41.5	41.6
Brown rice	42.4	42.6	--
Cut brown rice [b]	44.5	--	--
Milled rice	44.5	44.5	--

a/ Parboiled paddy prepared by RT' soaking, steaming at 0 psig for 60 min, shade dried.

b/ Hand-shelled brown rice grains cut into longitudinal halves.

Hence, the following procedure was adopted for this purpose. The paddy was put immediately into distilled water, after which the grains were individually cut longitudinally into two halves each with a sharp blade, their husks were removed by hand, and then the cut grains were left in water for the remaining period. It was ascertained that in actively retrograding material, quick cutting of the paddy in water (i.e. within about 15 min) was essential to get the correct EMC-S values, but removal of the husk could be delayed upto 2 hr without any detriment to the results.

However, whenever the EMC-S had to be determined in the parboiled paddy after drying, such paddy was hard and

hence difficult to cut, but easy to mill. Hence, in such cases, the EMC-S was determined in partially milled rice after milling the paddy in a hand rice miller (P. Colombini).

Moisture content of the sample was determined as described (Chapter II).

2.4. Hydrolysis of Starch in Rice by Glucoamylase

Rice flour (60-mesh, 100 mg) was taken in a test tube, 5 ml hot distilled water was added and the tube was immersed in a boiling water bath for 15 min with occasional stirring. After cooling, 4.5 ml of phosphate buffer (pH 5.5) was added, the tube was equilibrated in a 38°C water bath for 10 min, and 0.5 ml glucoamylase enzyme solution (containing 0.9 mg protein) was added with mixing. After standing for 30 min at 38° with occasional shaking, enzyme action was stopped by adding 2.5 ml of 2N NaOH and the volume was made to 50 ml. Reducing sugar was estimated in aliquots by titrimetric method of SHAFFER-SOMOGYI (AOAC 1970, method 31.054).

3.0. RESULTS

3.1. Test for Starch Retrogradation

A simple test for starch retrogradation was first sought. It was reasoned that any retrogradation would reduce the water-imbibing capacity of rice. Hydration of the samples was, therefore, sought to be used as a test for retrogradation.

Water-uptake values (W_{96}, W_{60}) were first tested. A portion of a sample of parboiled paddy was quickly dried with hot air and milled. The water-uptake value of the resulting rice was compared with those of rice milled from the same paddy after some period of storage as well as after slow drying in the shade. However, the samples showed little differences in their W values both at 60° and at 96°C, suggesting that changes if any occurred soon after the paddy had been steamed.

Drying and milling of the paddy were therefore abandoned, and the study of water uptake was replaced by that of EMC-S in the paddy itself. This immediately led to success, for the EMC-S of the material sharply decreased with time (see below). These results also showed that the EMC-S test was an excellent and simple tool to study starch retrogradation in precooked starchy products.

3.2. Retrogradation in Parboiled Rice

The EMC-S of parboiled paddy determined right after steaming was much higher than that observed after usual shade drying (Table 15). This demonstrated that the ability of the starch to hydrate had decreased during the intervening period, clearly as a result of some reassociation or retrogradation of the starch during the interval. Retrogradation of starch in parboiled rice following cooking and drying was thus confirmed. In fact, when the EMC-S was determined immediately after

Table 15

EMC-S of parboiled paddy before and after drying

Steaming of paddy for parboiling (min)	EMC-S (%, d.b.)	
	Immediately after steaming	After air drying a/
2	63.4	55.3
5	68.7	58.7
10	105.0	62.3
60	169.4	83.5

a/ Air dried in Laboratory for 2 days in shade

steaming and followed periodically at various intervals during shade drying, there was a gradual fall in the value over several hours ending in the familiar range normally observed in the milled produets (Fig. 23).

In a subsequent experiment, when freshly parboiled paddy was simply stored at room temperature in a closed container (without drying), its EMC-S value again showed a gradual fall with time of storage (RT curve, Fig. 24). This showed that starch retrogradation occurred with time, irrespective of drying of the wet parboiled paddy.

3.3. Effect of Temperature of Storage

The temperature of storage strongly influenced the fall in the EMC-S value, i.e. the extent of retrogradation.

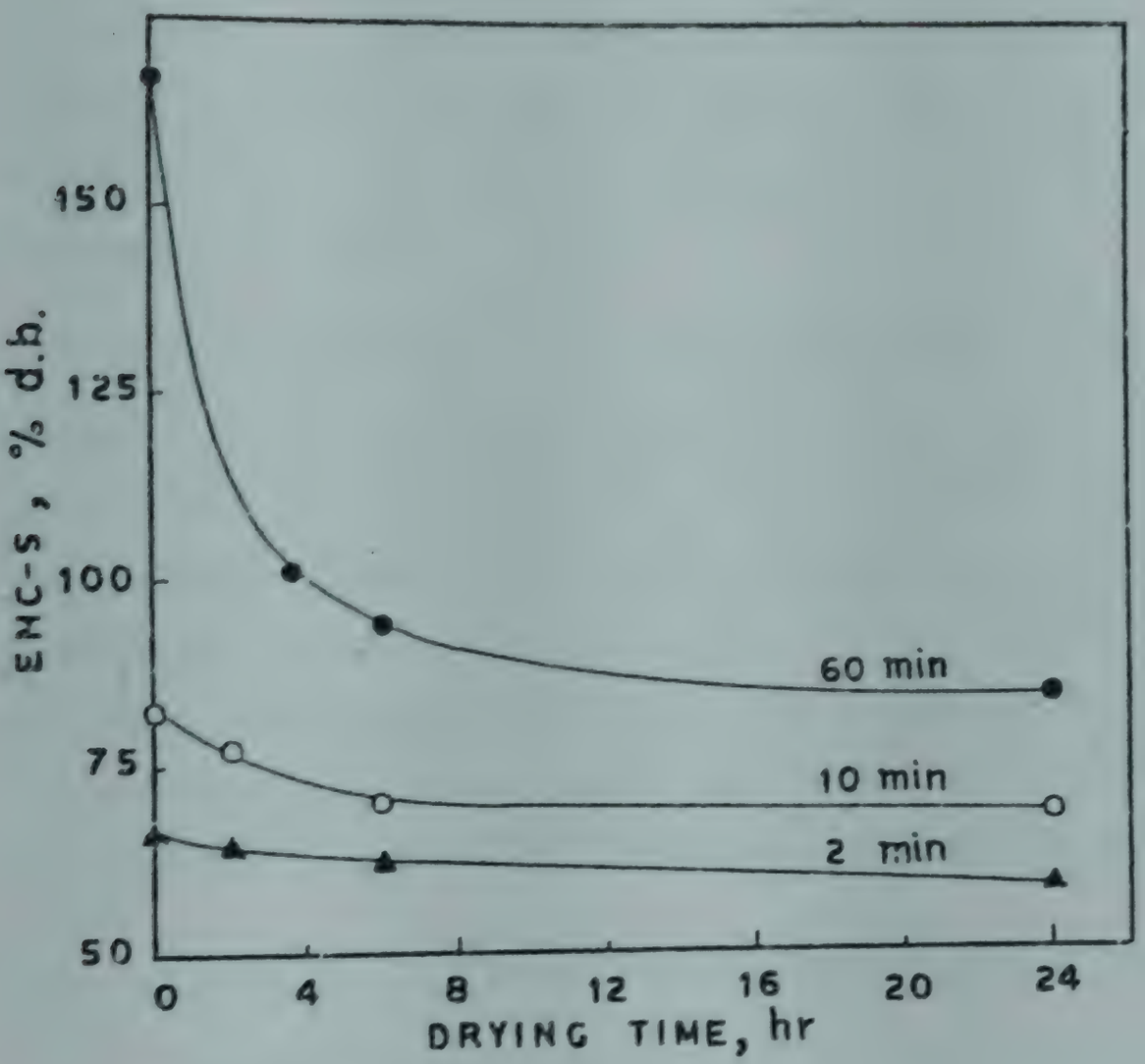


Fig. 23. Fall in EMC-S of parboiled paddy with progressive shade drying.

(Time of steaming during parboiling indicated)

Freshly parboiled paddy (60-min steamed) was transferred to tightly closed containers and stored at different temperatures. The EMC-S was determined periodically. The results (Fig. 24) show that the fall in EMC-S value (i.e. retrogradation) was maximum at room temperature (RT) and negligible at 95°C.

As a matter of fact retrogradation already developed in parboiled paddy, by being previously stored at RT, could be partially reversed by heating it (in closed tubes, to prevent loss of moisture), as shown in Fig. 25. About 2 hr heating was enough for this purpose. It is apparent from the curve that if the paddy were to be heated at 98°C (i.e. the steaming temperature during parboiling) the curve would have further projected and joined the value of initial EMC-S.

3.4. Effect of Moisture Content of Paddy during Storage

In view of the apparent lack of retrogradation in parboiled rice produced by sand roasting observed earlier (Chapter VII), the effect of moisture content of the paddy on changes in its hydration power after storage was studied.

A set of parboiled paddy samples with a wide range of moisture contents was prepared as follows: Freshly parboiled paddy (immediate EMC-S, 176% d.b.) was dried in shade and samples were drawn at various intervals to give a series of samples with decreasing moisture contents. Another portion of the same fresh parboiled paddy was soaked in warm water

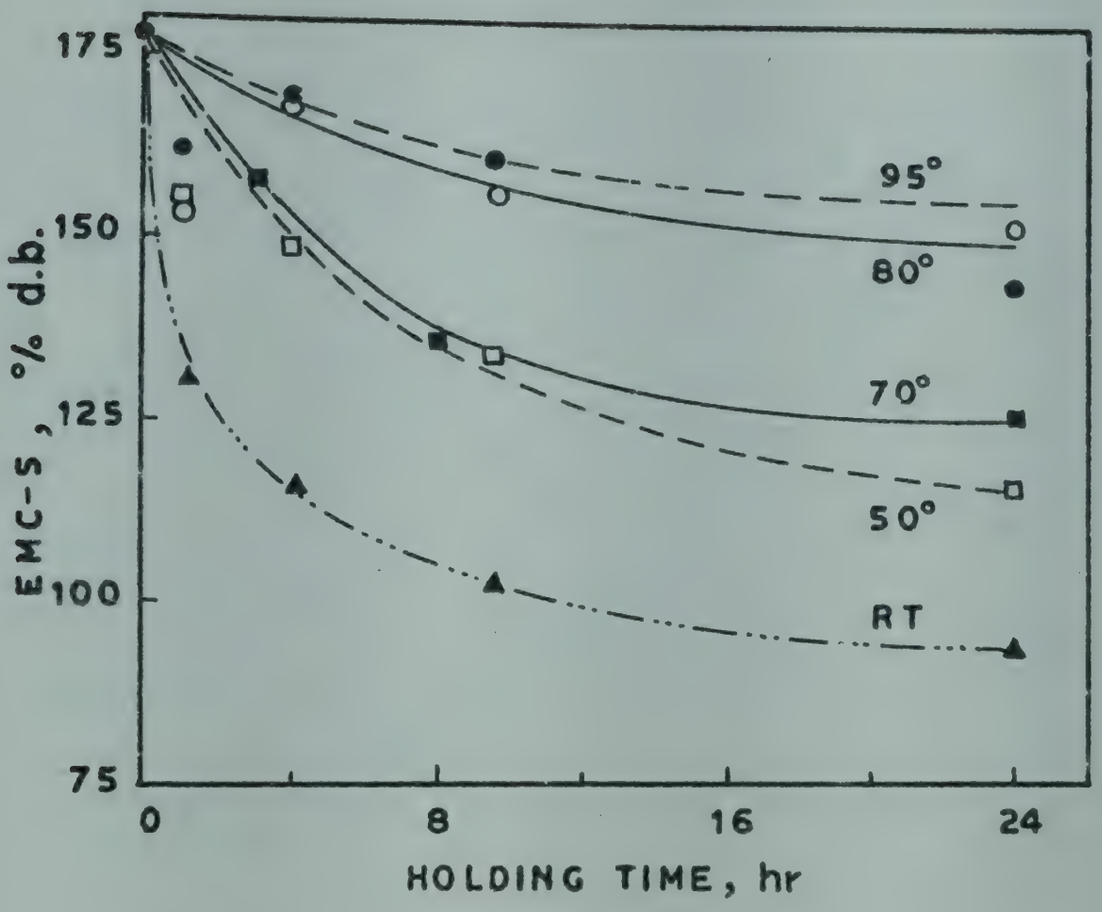


Fig. 24. Effect of temperature of holding on the fall in EMC-S of parboiled paddy with time.

(Paddy steamed for 60 min; moisture content as stored, 38.0% w.b.)

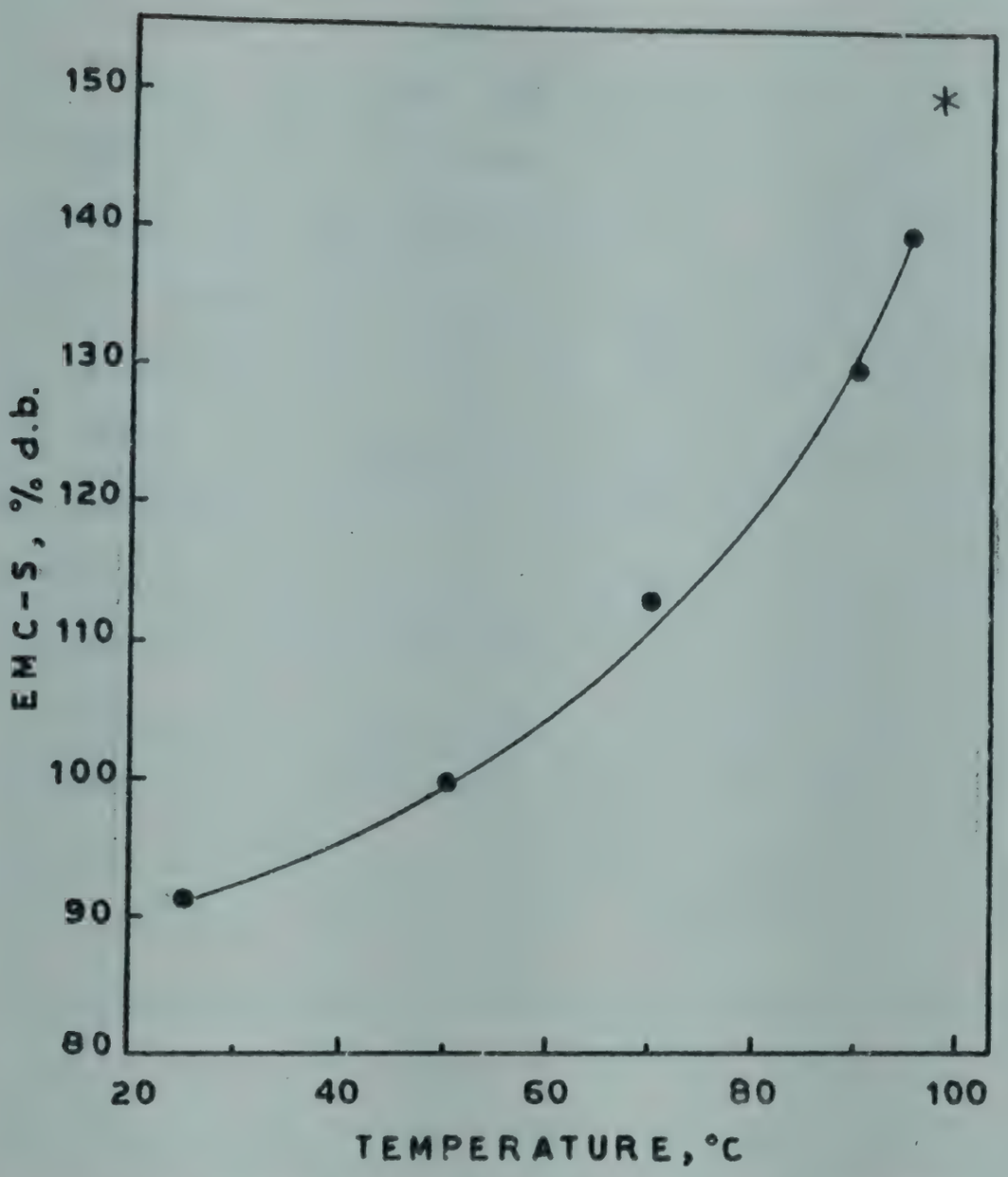


Fig. 25. Effect of heating of stored wet parboiled paddy on its EMC-S .

(Parboiled paddy, moisture content 36.7% w.b., stored at room temperature for 24 hr, then heated in closed tubes at different temperatures for 2 hr. The asterisk (*) indicates the EMC-S of original paddy immediately after steaming; the lowest point at bottom left represents the same paddy after storage but before heating.)

for different intervals to give another series of samples with higher moisture contents. All these samples were held for 24 hr at RT. When the EMC-S of these stored various-moisture samples was tested, the drop in EMC-S (i.e. retrogradation) was not identical in all. It varied among the samples, being the maximum at about 25% moisture content of the paddy (Fig. 26, curve a). The right half of this curve was rather flat, suggesting as if the low-moisture samples too underwent appreciable retrogradation. However, it should be remembered that in this case the low-moisture samples were obtained by relatively slow drying in the shade. In other words, these samples had already passed slowly through the moisture range where the retrogradation was maximum (24-30%), when they would have undergone appreciable retrogradation at that stage. Therefore, the fairly high retrogradation seen in these samples could well have been an artefact caused by the above factor. That this was so was proved by studies with roasted rice (see later in Chapter IX). In other words, the right half of the EMC-S - moisture content curve a should have been much raised, giving it a fairly sharp V shape.

Secondly, in another experiment, the fresh parboiled paddy in the above study was first held at its original moisture content (37.6% w.b.) and then dried to various moistures as above. When their EMC-S were determined immediately after drying (curve b), the curve did not show any retrogradation

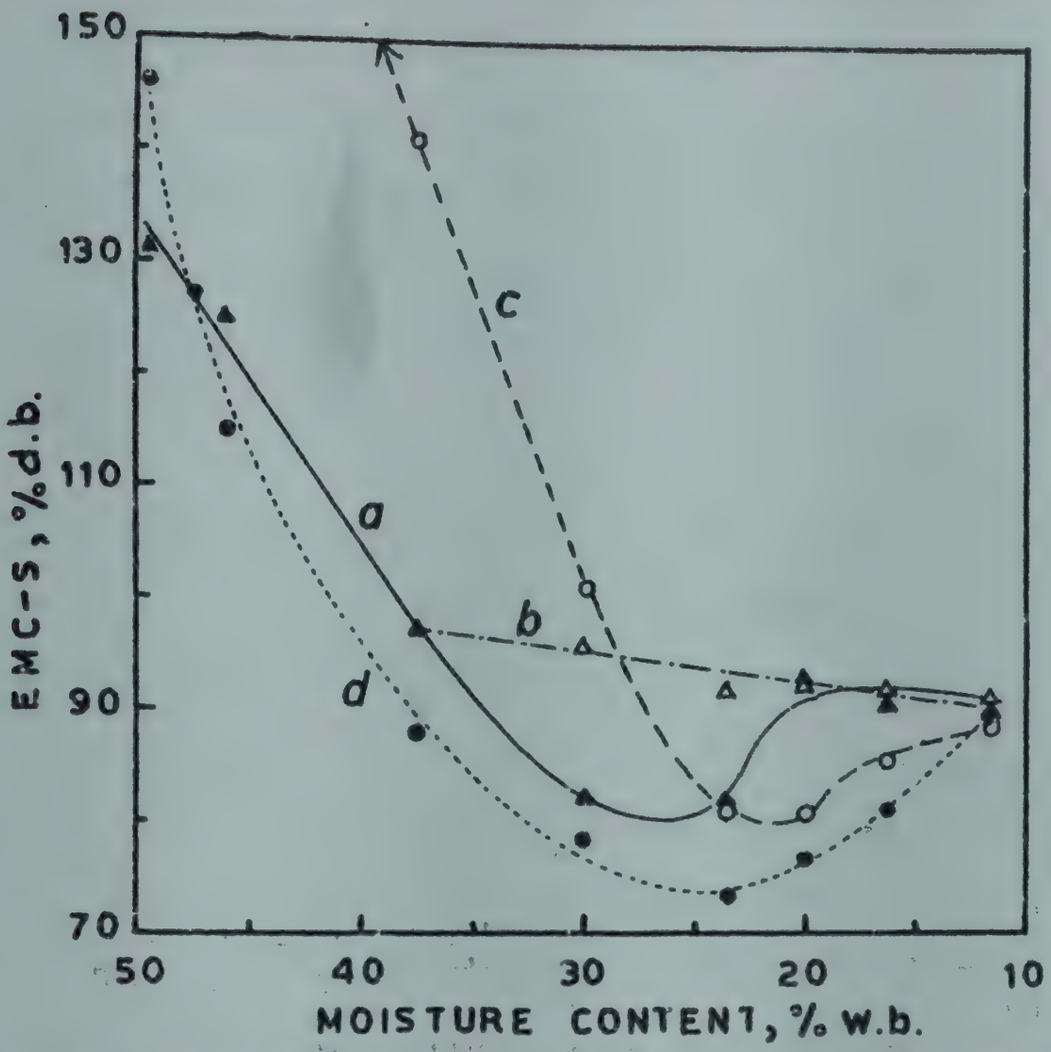


Fig. 26. Effect of moisture content of parboiled paddy on its starch retrogradation.
(a) steamed paddy immediately shade dried, or mixed with water to different moisture contents and held (RT, 24 hr); (b) steamed paddy first held and then shade dried to different moisture contents (not further held); (c) sample in 'a' heated in closed tubes at 95° (2 hr); (d) samples in 'c' held at RT (24 hr).

(Moisture content of initial steamed paddy 37.6% w.b.; its initial EMC-S 176% d.b. The arrow in curve 'c' indicates that the curve goes up linearly (cutting the Y axis at an EMC-S of about 210%).)

maximum, obviously because the samples did not have time to retrograde sufficiently at these moisture contents. This was proved by the fact that the curve reverted to more or less the curve a when these samples were again held (data not shown for the sake of clarity in the graph).

In a third experiment, the samples in curve a, after moisture adjustment and holding, were heated at 95°C (2 hr) and their EMC-S were determined immediately. It was found (curve c) that the samples with moisture content greater than 25% now showed an increased EMC-S (i.e. reversal of retrogradation), the extent increasing with increasing content of moisture; but those having less than 25% moisture showed actually an increased retrogradation now (though the latter effect was small in very low-moisture samples). In other words, the second half of the curve a now shifted slightly to the right, with the result that the retrogradation maximum now occurred at 20-25% moisture (instead of at 25-30% as observed after RT holding).

Fourthly, when the above heated samples of curve c were again held at RT, the curve reverted more or less to curve a except in the low-moisture portion which continued to remain low (curve d).

These results show clearly that retrogradation was maximum at a definite moisture content, falling off on either side, but this optimum moisture content itself decreased with

increasing temperature of storage and vice versa. This was further confirmed in another experiment where samples similar to curve a (Fig. 26) were held at 8°C (in a refrigerator) instead of at RT; the whole curve now shifted to the left with the maximum retrogradation occurring at 30-35% moisture content (not shown).

The effect of moisture content was further brought out as follows: When the sample corresponding to 23.4% moisture in curve a (near the retrogradation maximum: EMC-S, 83.5%) was either wetted or dried and further held, the new samples continued to show the same low EMC-S as before -- evidently because the severe retrogradation already achieved earlier could not be now undone. But when the 17.6% moisture-held sample was similarly adjusted to 26.4% moisture and held, its EMC-S dropped from 92% to 82% -- because now it retrograded further.

In another set of experiments, freshly parboiled paddy was quickly dried in a single-grain layer with hot air to 20.6% moisture, followed by finish drying in the shade, and held. This portion gave a much higher EMC-S value (117%) compared to another portion that was dried slowly in the shade and then held (95%), showing the retarding effect of quick drying on starch retrogradation. Similarly, when milled raw rice was soaked in water and steamed for 10 min, simulating parboiling, it gave the following EMC-S results: immediate, 160%; after quick hot-air drying and holding, 156%;

after first holding at RT for 5 hr and then shade drying, 107%.

3.5. Test of Retrogradation by Enzyme Hydrolysis

The occurrence of starch retrogradation in normal parboiled rice was further confirmed by preliminary studies on the hydrolysis of starch in the rice flour by glucoamylase. Release of glucose from the parboiled rice flour was significantly less when compared to from raw rice. The decrease was proportional to the severity of parboiling. Thus, under the conditions of the test employed, the release of glucose by the enzyme was only 88% in mild parboiled (10 min steamed) and 73% in severely parboiled (60 min steamed) rice of that in raw rice. These data were also in line with the lower hydration ability and amylose solubility of parboiled rice.

3.6. Reversal of Retrogradation

Data in Fig. 25 and in Fig. 26 (curve c) gave indication that preformed retrogradation in parboiled rice could be reversed by heating under certain conditions. In view of the economic importance of this subject (reversal of retrogradation will reduce the time of cooking of the rice and hence save domestic fuel), this aspect was further studied with milled parboiled rice.

Milled parboiled rice was soaked in water and portions were collected after various periods of soaking to give a set of samples with different moisture contents ranging from 14%

to 44% (w.b.). The samples were held in closed tubes overnight for the equilibration of moisture content, and then heated at various temperatures (50°-95°C) for 2 hr. Their EMC-S were determined immediately at the end of heating and after further holding for 24 hr. The results are presented in Fig. 27. As in the case of steamed paddy, the increase in EMC-S (i.e. reversal of retrogradation) on heating was proportional to the temperature of heating and the moisture content of the sample. Samples having a moisture content of 30% or less showed very poor or no reversal. In fact 21.1% and 13.9% moisture samples showed further drop in EMC-S after heating (as also observed earlier in the case of paddy). Appreciable reversal effect could be noticed in the 38% moisture sample. And when milled parboiled rice was soaked to its EMC-S level (43.9% moisture, w.b.) and then heated at 95° for 2 hr, its EMC-S value reached a level comparable to the value given by the corresponding parboiled paddy immediately after steaming (about 150%, d.b.), indicating more or less complete reversal.

These results thus showed that appreciable reversal of the starch retrogradation in parboiled rice could not be achieved under mild conditions, but required rather high levels of moisture and temperature. Further studies in this direction are needed.

4.0. DISCUSSION

The present data clearly demonstrate the occurrence of some reassociation or retrogradation of starch in normal

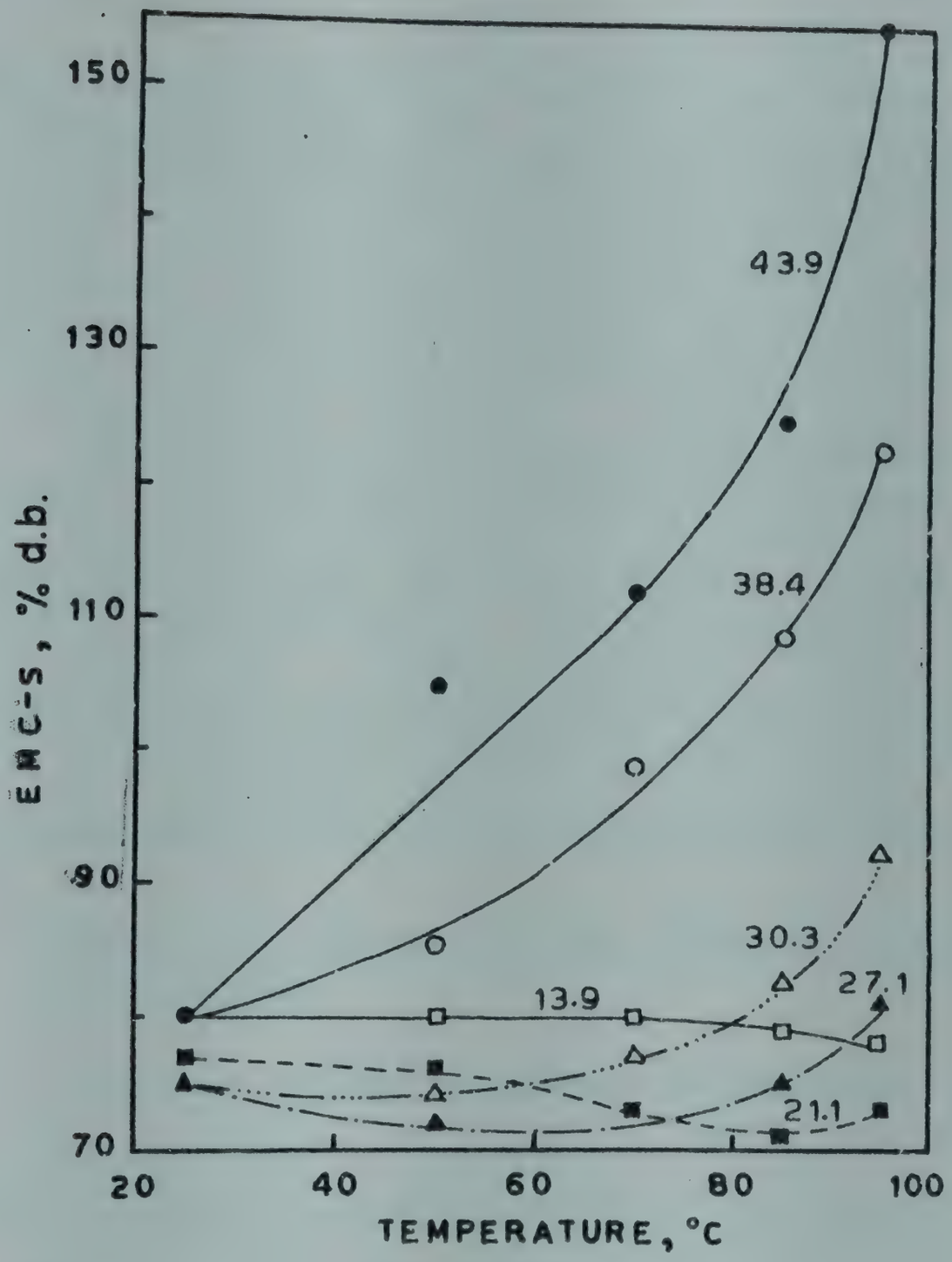


Fig. 27. Effect of heating milled parboiled rice of different moisture contents on its EMC-S.

(Milled parboiled rice, with 13.9% w.b. moisture, adjusted to different moisture contents as indicated, held at RT, then heated for 2 hr.)

parboiled rice and also explain the reasons thereof. As normally prepared in commerce, parboiled paddy contains 35-40% moisture immediately after steaming which is then reduced by drying (in sun or by heated air) to 12-14% moisture over some time interval. Naturally, as seen above in the effect of moisture, the end product shows severe retrogradation.

The fact that retrogradation in parboiled rice could be partly reversed by simple heating (Figs. 25, 26, 27) suggests that a part of the bonding forces are perhaps rather weak or are unstable to heat. Such heat-reversal of the staling of bread is well known (MAGA 1975) and has been interpreted to indicate the involvement of amylopectin rather than amylose molecules in the staling process (SCHOCH 1965).

4.1. Effect of Moisture Content and Temperature on Starch Retrogradation

The most striking observations of the present study are the rather puzzling interconnected effects of moisture content and temperature on the extent of retrogradation. At any given temperature there was an optimum moisture content at which the retrogradation was maximum; but this optimum rose or fell as the storage temperature was lowered or raised respectively. In other words, neither the moisture content nor the temperature uniquely determined the extent of retrogradation but a combination of both did. Also, increase or decrease in either of them did not uniquely determine whether

the retrogradation would increase or decrease; either could happen depending upon the specific values of the two factors. For example, increasing the temperature of storage from RT to 70°C decreased the extent of retrogradation if the moisture content of the rice was (say) 35% but increased it if the moisture was (say) 15%. So with the moisture : increasing the moisture from 25% to 35% (say) decreased the retrogradation at 25° but increased it at 8°C and so on.

Earlier workers too observed that the extent of starch retrogradation is affected by the temperature and moisture content; but generally only their individual effects were noted and these effects were generally found to be unidirectional (MAGA 1975, COLLISON 1968). The complex interdependent and bi-directional effects as seen here do not appear to have been observed before -- no doubt because starch retrogradation has been but little studied so far in such intermediate-moisture products as processed rice. Systems such as these may thus provide a useful vehicle for a deeper study of the process of starch retrogradation.

The rather puzzling behaviours of temperature and moisture content may perhaps be explained as follows:

Starch retrogradation implies the growth of relatively insoluble molecular aggregates by secondary forces, presumably hydrogen bonds, between neighbouring linear molecules or linear segments of branched molecules. It therefore requires

previous parallel alignment of the molecules and so would be influenced by their free movement (somewhat akin to Brownian movement). Too high a moisture content or temperature apparently raises the free movement or thermal vibration so much that a favourable molecular alignment does not remain sufficiently stable for bonding to follow. Too low a moisture on the other hand probably lowers the motions or vibrations so sharply that the sluggish molecules cannot align suitably for bonds to be formed. Retrogradation is prevented or retarded in either case.

However, the above explanation may need further elaboration. It does not explain for instance how an exothermic process like hydrogen-bonding (if this be the bond in retrogradation) is facilitated by heating under certain conditions (e.g. retrogradation in parboiled rice having 15% moisture is more at 70°C than at RT). A deeper study of the process of starch retrogradation and of the energetics involved is needed.

4.2. Practical Implications

From the practical standpoint, the following points deserve attention: Starch retrogradation in parboiled rice lowers its rate of hydration and so raises the time and cost of its cooking. Measures to retard or prevent this phenomenon would therefore be of practical interest. Prevention of retrogradation, as seen, would imply gelatinization in such a way that the moisture content is simultaneously and rapidly

reduced -- such as by roasting (conduction heating), perhaps heating by very hot air, etc. As for reversal of preformed retrogradation, there was some indication that this could be achieved by suitable heat treatment. Although preliminary work reported on this line has not given very encouraging results, further work is desirable. Pursuing of these aspects should be of practical value.

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Chapter IX

NATURE OF ROASTED AND FLAKED RICE

1.0. INTRODUCTION

Work reported in Chapter VII suggested that starch retrogradation was perhaps prevented or reduced in parboiled rice prepared by sand-roasting of soaked paddy (henceforth called roasted-parboiled rice, or simply roasted rice) as the moisture was quickly driven off during gelatinization by roasting. This view was supported by results presented in Chapter VIII, which showed that a low moisture content indeed reduced starch retrogradation. A direct study of this aspect was undertaken in the line of studies presented in Chapter VIII.

Earlier work (Chapter VII) also showed that some further change seemed to occur in flaked rice during the flaking step. This too was proposed to be clarified.

2.0. MATERIALS AND METHODS

2.1. Paddy

Ratnachudi paddy, procured from University of Agricultural Sciences Regional Research Station at Mandya, was used. It was 6 months old after harvest when the study was initiated.

Details of parboiling and milling have been described (Chapter II).

2.2. Roasting

To simulate commercial operations in the laboratory under controlled conditions, a small hand-operated and electrically-heated coffee roaster (about 0.5 kg capacity, 20 cm long x 15 cm dia, with a hopper at the inlet-cum-discharge end) and provided with vertical baffles for uniform mixing and a thermostatic control was used. Roasting was done with sand; 100 g of soaked paddy and 200 g of sand (-22 +60 mesh, washed and dried) were used in each experiment. The temperature was noted from a thermometer inserted through the open inlet-cum-discharge end.

The procedure was to heat up the roaster with sand, while being manually rotated (about 20 rpm), to a specified temperature and maintain it for a few minutes. At this point the heater was switched off, paddy was quickly added and rotation was continued for the desired time (several seconds to a few minutes). After roasting, the mixture was discharged on to a sieve (about 12-mesh) to remove the sand.

2.2.1. Temperatures of roasting: These values indicated in the text below are the nominal temperatures, i.e. the temperature to which the roaster was adjusted before the paddy was added. The true roasting temperature was quite

different because there was a considerable drop of the sand temperature as soon as the paddy was introduced in the roasting chamber. This reduced temperature then slowly rose for 3-5 min and then remained more or less constant for a short while at an intermediate value. The various nominal temperatures employed and the corresponding approximate related temperatures under the experimental conditions are indicated below:

Nominal temperature	Immediate temperature (on adding paddy)	Stable temperature attained	Temperature attained by paddy after 5-10 min roasting	Puffing	Charring (at 5 min)
		(°C)			
200	105	130	118	-	-
250	110	175	160	±	-
300	140	200	185	+	-
350	180	235	220	++++	+

2.3. Flaking

Flaking of the roasted paddy, simulating commercial preparation of flaked rice (Chapter VII), was carried out in 10-15 g lots in a small mild-steel mortar and pestle. The roasted grains were pounded for 30-60 sec till the husk and a portion of the bran were removed and the endosperm flattened. The mixture was sieved in a 12-mesh screen and then winnowed

by blowing from the mouth. It was observed that best flaking could be achieved after roasting paddy at 250°C and above (nominal temperatures) till the paddy moisture was reduced to 17-20% (w.b.) and flaking it while it was still hot. Hence in the present studies, there was considerable variation in the extent of flaking among the different experimental lots which might have introduced some variation in the results.

2.4. Moisture Content of Various Samples

After roasting and sieving out the sand, the roasted paddy was immediately transferred to a thick paper carton, covered with several folds of cloth. At least three lots of 10-15 g each were drawn from this and flaked as described above and the various subsequent operations carried out. These steps took 5-10 min during which the hot paddy lost a certain amount of moisture. The moisture contents indicated below are therefore not the true moistures of the paddy as obtaining immediately after roasting but those attained after the above operations at which point it was actually 'held' for experimental purpose. The true moisture contents were 1.5 - 5 percentage points more than those indicated, the difference being more at higher temperatures of roasting and higher paddy moistures and vice versa. Similarly, the moisture contents of flaked rice indicated are the mean moisture of the 3-4 sublots prepared as above. The moisture content of the flaked rice was always higher by 2-2.5 percentage points than

that of the corresponding paddy from which it was flaked, indicating the dry state of the husk and bran layers after roasting.

2.5. Holding and EMC-S

Samples were 'held' for experimental storage at different temperatures, and the equilibrium moisture content attained by them upon soaking in water at room temperatures (EMC-S) was tested as described in the previous Chapter. In case of roasted paddy, it was quickly milled partially in a hand rice miller (P. Colombini) before determining the EMC-S.

3.0. RESULTS

3.1. EMC-S of Roasted and Flaked Rice

Soaked paddy was roasted at nominal temperatures of 200, 250, 300 and 350°C for varying times and then flaked. The progressive loss of moisture from paddy on roasting under the above four conditions is shown in Fig. 28.

EMC-S was determined in the above samples: (a) immediately after roasting and flaking, and also (b) after holding at RT and 70°C. The results are presented in Fig. 29.

3.1.1. Effect of roasting on immediate EMC-S: The immediate EMC-S of paddy rose from about 38% in untreated paddy to as much as 100-250% on roasting, depending on its duration and temperature. This was clearly as a result of gelatinization brought about by the heat treatment. The rise

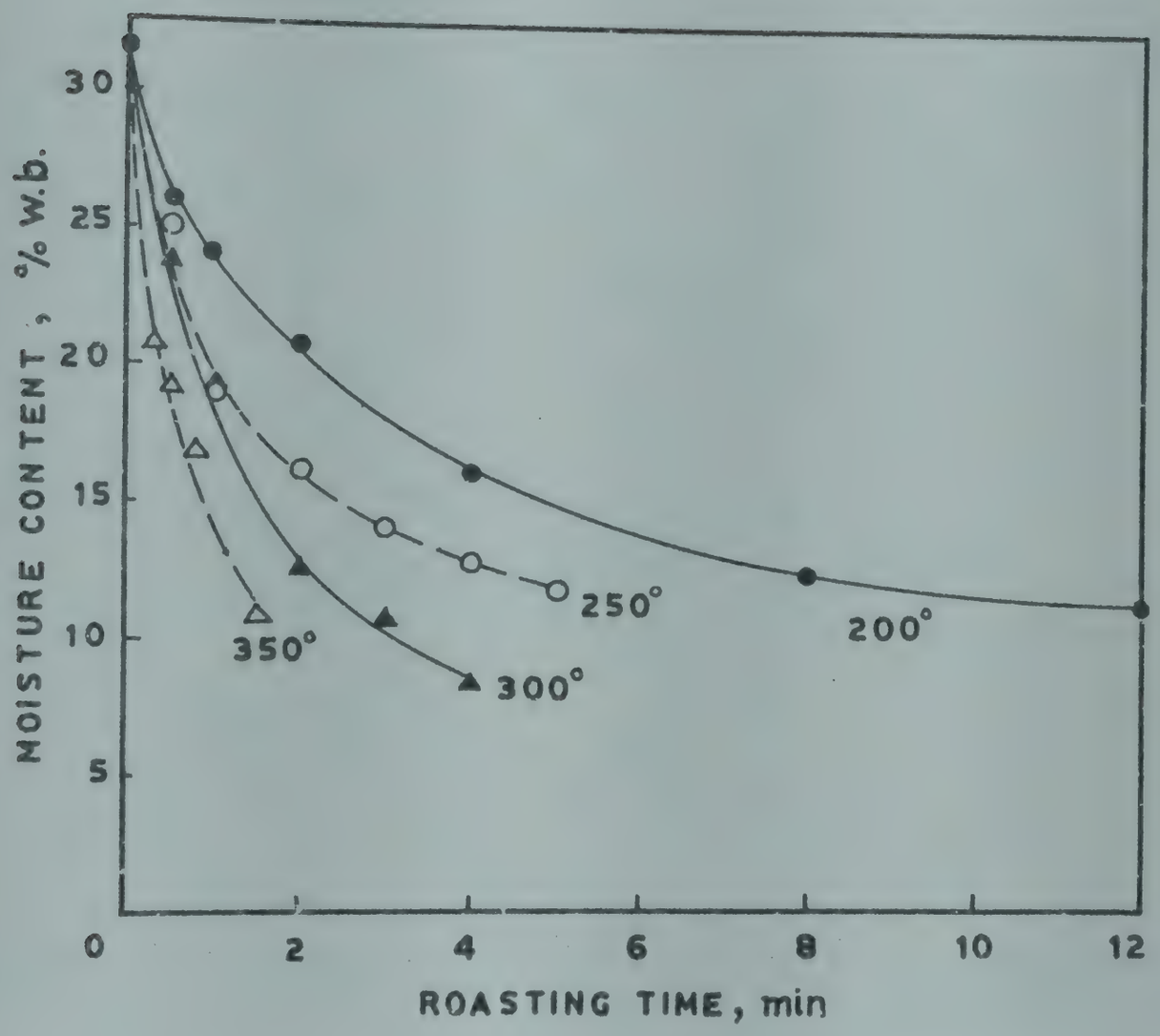


Fig. 28. Progressive fall in moisture content of soaked paddy during roasting at different nominal temperatures.

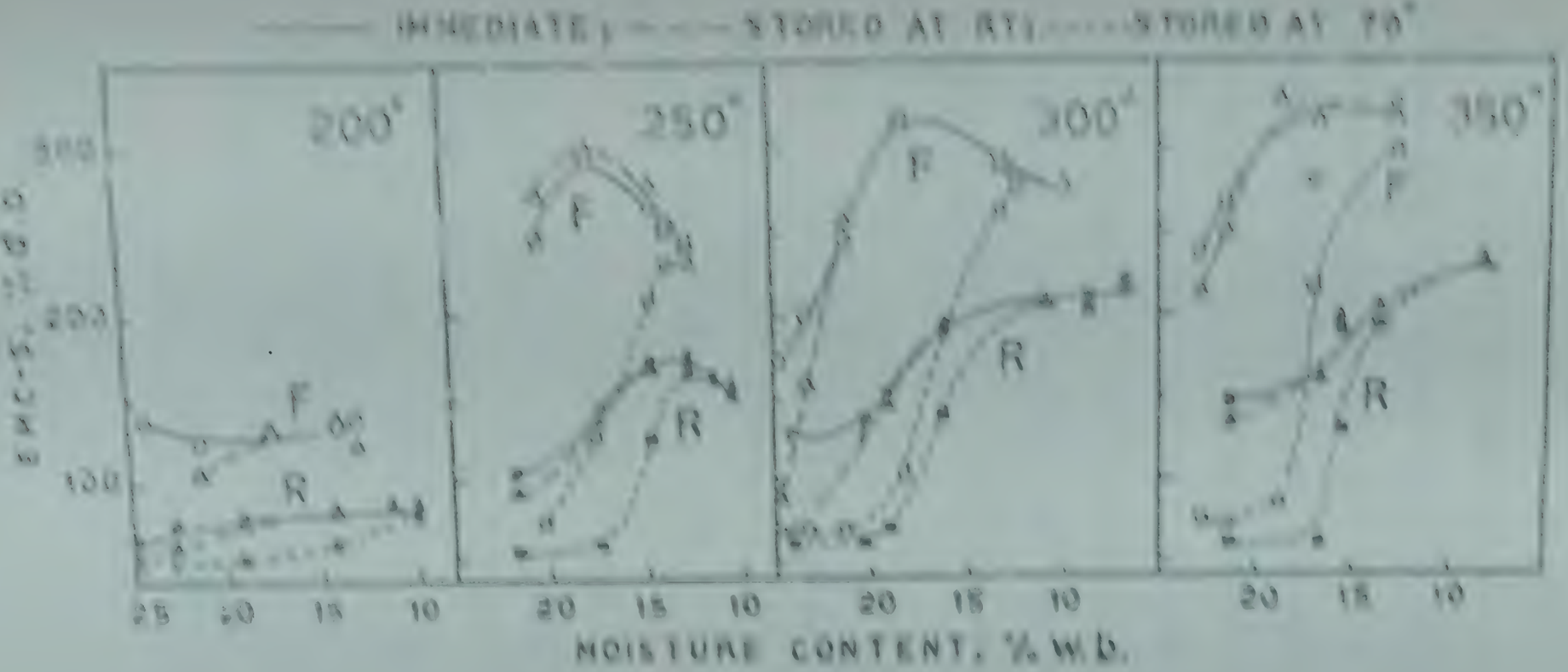


Fig. 29. [illegible] of roasted paddy and flaked rice as obtained and after storage;

(Broken rabbi roasted at indicated temperatures for different times, i.e. to different colours stated, and flaked. Broth of roasted paddy, R, and flaked rice, F, determined before and after storage at RT and 70°C (for 24 hr.)

was minimal at 200°C where the highest EMC-S (80-85% moisture) was achieved only after 4-8 min of roasting by which time the moisture content of paddy fell to about 15-19% and the latter attained a temperature of 115-120°C. The rise in EMC-S was substantial after roasting at 250°C where the maximum EMC-S (about 170% moisture) was achieved after 2 min of roasting, at which point the moisture content of paddy was reduced to around 15% and it attained a temperature of about 140-150°C. With further increase of roasting temperature to 300 & 350°C, the immediate EMC-S values rose further somewhat (to nearly 200-230% moisture), but there was some danger of puffing and charring.

3.1.2. Effect of flaking: The immediate EMC-S of flaked rice, as observed earlier (Chapter VII), was still higher than that of roasted rice from which it was flaked.

This increase in EMC-S due to flaking was again the least in the 200°C roasted paddy (50-60% moisture more) but substantially higher in the sample roasted at 250°C or more (100-130% higher moisture). The maximum increase occurred when the paddy was flaked at a moisture content of about 17-20% and after it had been roasted at temperatures of 250° or more.

3.1.3. Retrogradation during storage: When stored at RT, there was practically no retrogradation (i.e. drop in EMC-S), either in roasted rice or flaked rice, when its moisture content was below 18%. This result explained the

high hydration capability of these forms of processed rice seen earlier (Chapter VII). But that this was only due to a lack of sufficient moisture was shown by the fact that retrogradation did occur, with increasing severity, in the samples having greater moisture. The results also confirmed the earlier speculation that the true moisture content-EMC-S curve (such as curve a, Fig. 26) is a sharp V. However, the point of retrogradation maximum could not be seen here as no sample of either roasted or flaked rice had over 25% moisture.

On holding at 70°C (24 hr), on the other hand, retrogradation was absent only at 12% moisture or less; it became severe and progressive in the range of 15-18% moisture after which the effect tapered off. The interrelation between moisture content and temperature with respect to retrogradation seen earlier in parboiled rice was thus evident in these products also.

3.1.4. Induced Retrogradation in Roasted and Flaked Rice: Retrogradation could also be induced in dry roasted or flaked rice by artificially increasing the moisture content. When a sample of soaked paddy was roasted to 16.2% moisture, it showed an immediate EMC-S value of 206%. A part of it, which was held at RT in a closed tube, showed only a slight drop in EMC-S (to 191%). But when another part of the original roasted paddy was adjusted to 35% moisture (w.b.) by addition of water (simulating the moisture of normal steam

parboiled paddy) and held at RT overnight, its EMC-S value dropped to 79.4%, exhibiting a very high retrogradation, the value being in the same range as that observed for normal steam-parboiled rice. Similarly, when a sample of flaked rice, showing an EMC-S of 410% was adjusted to 33.9% moisture by addition of water and then held, its EMC-S showed a dramatic drop to 114%.

Clearly, roasted and flaked rice, though apparently different from parboiled rice, are essentially similar to it and behaved as such when the moisture content or storage temperatures were adjusted appropriately.

3.2. Changes Occurring during Flaking

The unusually high EMC-S of flaked rice, however, remained to be explained. A separate study on the effect of flaking on various products was thus undertaken.

When wet, freshly parboiled paddy was pounded in the mortar as in making flaked rice, both when hot as well as after holding, the resulting products (though not properly flaked and partly disintegrated) had an increased EMC-S (Table 16), showing that the effect of pounding or flaking was not specific to roasted rice or to a hot state.

To test this aspect further, milled parboiled rice was adjusted to different moisture contents by soaking in water and held. A part of each sample was then flaked, a

Table 16

Effect of flaking (pounding) on EMC-S of rice

Material	Moisture content to which adjusted (%, w.b.)	EMC-S (%, d.b.)		
		Before pounding	After pounding	
			in mortar	on bench
Parboiled Paddy:				
Just steamed	36.7 a/	160.0	264.0	--
Held	36.7 a/	84.5	117.0	--
Parboiled milled Rice	14.6	73.6	87.7	99.2
	19.5	70.2	86.5	87.7
	21.5	72.5	88.5	91.5
	23.0	71.4	89.8	98.5
	26.4	70.6	90.7	109.6
	30.5	66.7	92.0	109.0
Raw milled rice	16.3	37.5	--	46.9
	19.3	37.0	--	55.1
	27.1	40.9	--	56.7

a/ Moisture content of paddy as parboiled, not adjusted

part was steamed at 0 psig for 2 min (to see the effect of hot flaking), a part of which was again immediately flaked. As the grains tended to break instead of flaking when pounded in the mortar, they were flaked by direct flat hits on the individual grains on a tiled cement bench. It was observed (Fig. 30) that there was an appreciable increase in the EMC-S on flaking

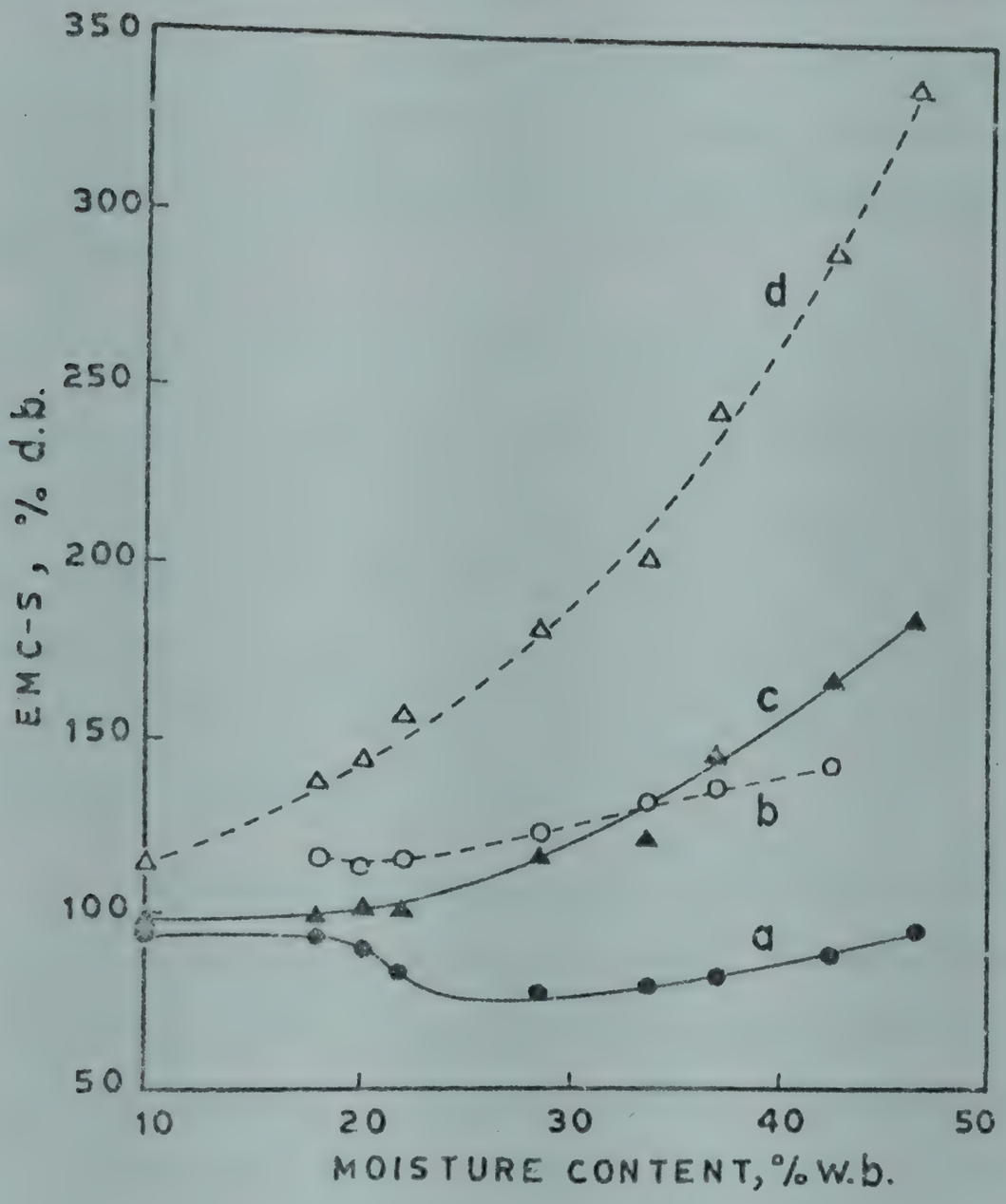


Fig. 30. Effect of flaking on the EMC-S of milled parboiled rice, adjusted to different moisture contents, before and after steaming. (a) parboiled rice held; (b) 'a' flaked; (c) 'a' open steamed 2 min;(d) 'c' immediately flaked.

both before and after steaming (the steaming too considerably raised the EMC-S, possibly by reversal of the preformed retrogradation). When pounded in the mortar, the grains broke more than were flattened and the rise in EMC-S was considerably less (Table 16).

Similar tests were carried out with raw milled rice. In this case flaking (even individually) was still more difficult, the low-moisture samples in particular usually breaking and flying off at the moment of impact. The results (Table 16) showed that even in the case of raw rice there was an increase in the EMC-S when the moisture content was sufficiently high to enable reasonable flaking.

It could thus be seen that increase in hydration power was a natural corollary of all flaking, irrespective of the form of rice used. The effect of flaking however increased with the increase in moisture content and temperature -- probably because these conditions facilitated better flaking. Moreover, parboiled rice appeared to be more prone to such change compared to raw rice. Thus when milled parboiled rice (air-dried) was ground to about 30 mesh in a Buhler disc mill, the EMC-S of the powder (124%) was considerably higher than that of the whole rice (93.1%). But the EMC-S of raw milled rice (38.7%) was not affected by similar powdering.

4.0. DISCUSSION

4.1. Properties of Roasted-Parboiled Rice

The above results clearly explain the peculiar properties of roasted rice. Though apparently different from parboiled rice, it was essentially similar to the latter but behaved differently because of the circumstances of its production. As normally produced, the roasted paddy contains no more than about 17-20% moisture (w.b.) which, coupled with the normal room-temperature storage, inhibits further retrogradation. Hence its relatively high hydration and cold-swelling behaviour. However, when so produced, or adjusted, to have a high moisture content, or when stored at a high temperature, roasted rice too showed a high retrogradation and behaved just like normal parboiled rice. The earlier speculation about the high hydration power of roasted rice being caused by its quick and simultaneous dehydration during roasting, is thus confirmed.

4.2. Starch Damage during Flaking

While the same reasoning as above applies partly to flaked rice also, retarded or reduced retrogradation alone cannot explain the further enhanced hydration capacity of flaked rice over that of the roasted rice from which it is flaked.

The results of flaking experiments (Table 16, Fig. 30) show that increase in EMC-S occurred whenever there was genuine

flaking but not, or less so, when the grain merely broke and flew away in pieces under the impact of pounding. Also it occurred irrespective of whether the rice was raw, parboiled or roasted, hot or cold. The only explanation seems to be that on flaking the stress was absorbed by the entire kernel body, there was plastic (or visco-elastic) deformation, and hence the starch granules underwent mechanical damage -- which naturally raised their hydration power. But on simple breaking, it was more a case of elastic failure without significant plastic deformation, when fracture probably occurred along cell walls, leaving the granules undamaged -- and hence the EMC-S did not change significantly. As a higher moisture content or temperature renders more plasticity to the material, these factors probably for this reason enhanced the extent of flaking, and hence the increase in EMC-S, as can be seen from the data in Table 16 and Fig. 30. The increase in the observed EMC-S of flaked rice over that of roasted rice and its high cold-swelling behaviour thus appeared to arise from starch damage during flaking.

Such starch damage may indeed partly explain the cold-swelling behaviour of many flaked, puffed or otherwise deformed cereal products. Further work in this direction with a concurrent study of the mechanical (visco-elastic) properties of cereal grains under different conditions of moisture and temperature would provide a fruitful field of research.

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Chapter X

CHANGES IN FREE SUGARS AND AMINO ACIDS DURING PARBOILING

1.0. INTRODUCTION

There has been evidence that milled parboiled rice contains more reducing sugars than milled raw rice (WILLIAMS & BEVENUE 1953). This was attributed to the inward diffusion of sugars from the bran layer during the parboiling process.

On the other hand, the increased sugar content might well arise from biochemical reactions during soaking of paddy, as the soaking step could be considered to represent the initial phase of germination. Considerable amount of literature has been accumulated on the changes that take place during seed germination, which indicate a rise in the rate of respiration and an increase in activity of various hydrolytic and synthesizing enzymes (McLEOD et al 1964, BROWN 1972). Studies concerning rice germination have, similarly, shown the development of amylases, proteases and other hydrolytic enzymes (FUKUI & NIKUNI 1956, SIRCAR & DUTTA RAY 1962, MURATA et al 1968, TANAKA et al 1970, PALMIANO & JULIANO 1972, 1973). However, studies covering early phase of seed germination have been scanty, although indications of an active state of metabolism do exist (McNAIR 1966, ABDUL BAKI 1969, BROWN 1972).

Sugars and amino acids released in the above manner, if any, would surely contribute to browning reaction and hence to the quality of the product. Possible development of sugars and amino acids in the grain during soaking was therefore studied.

2.0. MATERIALS AND METHODS

2.1. Material

Ratnachudi variety of paddy was used as in the case of other studies. The paddy was about an year old after harvest at the time of initiation of the studies.

2.2. Determination of Free Sugars and Amino Acids

2.2.1. Extraction: Initially, sugars were extracted in both 50% and 80% ethanol. Rice flour (0.5 g, 40-60 mesh) was heated in 10 ml aqueous alcohol at 82°C for 1.5 hr and allowed to stand overnight. Volume was made up to 20 ml, centrifuged, and the supernatant was decanted. Extraction with 80% ethanol did not show any advantage over 50% alcohol. On the other hand, 80% alcohol extract gave a faint opalescence. Use of 50% alcohol for extraction was thus resorted to.

Later studies showed that a more convenient procedure was to extract in distilled water (0.5 g powder in 10 ml) at boiling temperature for 20 min and then to make up the volume to 20 ml with distilled ethanol, after cooling, so that the final alcohol concentration remained at 50%. It was later centrifuged.

In the studies where whole grains or parts of the grains were used for extraction, they (0.5 g whole grain or degermed brown rice; 25 mg excised germ) were briefly boiled for 2-4 min in water (about 10 ml), decanted into a mortar and pestle, and then ground with 1-2 g acid-washed, clean sand (22-40 mesh). The mixture was transferred quantitatively back to the test tube, and boiled for a further 15 min, and then diluted with alcohol etc as before.

2.2.2. Determination of reducing sugars (RS): Two milli-litre aliquots of the extract were heated in a boiling water bath to evaporate off the alcohol till the volume was reduced to a little less than half. Distilled water was added to replace the evaporation loss approximately. The reducing sugars were then determined by the method of SOMOGYI (1952) using arsenomolybdate as the chromogenic reagent (NELSON 1944) and glucose as standard.

2.2.3. Determination of sucrose: Sucrose was hydrolysed by adding 0.5 ml 10N H_2SO_4 to 5 ml of the extract and heating it at 70°C for 10 min. The extract was cooled, neutralized using NaOH and diluted to a suitable volume before estimation of reducing sugars as described above. The difference in the reducing sugars before and after hydrolysis was taken as sucrose.

It was noted that careful pH adjustment of the hydrolysed extract during neutralization was very important for the

subsequent determination of reducing sugars. The results were very low on either side of neutral pH, alkaline pH being more detrimental.

The extract could be neutralized by shaking with excess Ba_2CO_3 but the process took a long time (1 hr). Phenolphthalein (pH 8.3-10.0) was unsuitable, but bromocresol purple (pH 5.4-7.0, yellow to blue) was suitable. A drop or two of the indicator was directly added to the extract and the latter neutralised; the indicator did not interfere with the subsequent colour development. Maximum colour was produced when the extracts were neutralized to a transitory colour (light yellowish green).

2.2.4. Determination of free amino acids (FAA): FAA in the extracts were analysed by the ninhydrin method of ROSEN (1957) using leucine as standard.

2.3. Incubation Experiments

For certain experiments, powdered or whole brown rice (sometimes milled rice) or degermed brown rice and embryos were incubated at different temperatures for different lengths of time. In such cases 0.5 g material (25 mg in case of excised embryos) in 10 ml distilled water was incubated, with the addition of 2-3 drops of chloroform and 0.5 ml toluene to prevent microbial growth, with occasional mixing. The toluene layer from the top of aqueous phase was sucked out carefully at

the end of incubation period before extraction of the sugars and FAA by boiling and adding alcohol etc as described earlier. Addition of other antimicrobial agents (chloramphenicol, thymol), or exposure to ultra-violet ray together with toluene and chloroform did not give any additional advantage.

2.4. Chromatography

10-15 ml extract taken in a 50-ml beaker was evaporated on a water bath to about 0.5-0.75 ml and then dried completely in a vacuum desiccator. The dry samples were redissolved in 0.5 ml of 50% alcohol and suitable aliquots were subjected to ascending paper partition chromatography with butanol : acetic acid : water (4:1:1) consecutively for 2-3 times (20-24 hr each). The air-dried paper was sprayed with aniline hydrogen phthalate solution and colour was developed by heating in an air-oven at 110°C for 15 min (MISRA & MOHAN RAO 1960).

2.4.1. Desalting of hydrolysed extracts: The samples which were subjected to acid treatment for sucrose hydrolysis did not give clear separation of sugar spots but showed a trailing effect. Desalting by raising the alcohol concentration to 67%, or hydrolysis by perchloric acid followed by neutralization with KOH did not show any improvement. However, neutralization with $Ba(OH)_2$ after hydrolyzing the extracts with H_2SO_4 was effective. This gave clear sugar spots without any trailing.

3.0. RESULTS

3.1. Contents of Sugars and Free Amino Acids in Rice and Effect of Milling

The contents of sugars and free amino acids in different forms of raw and parboiled rice are presented in Table 17. In raw rice, sucrose and free amino acids were

Table 17

Contents of sugars and free amino acids in different forms of raw and parboiled rice

Material	Sugars (%)		Free amino acids (mmoles/100 g)
	Reducing	Sucrose	
Raw:			
Paddy	0.20	0.75	--
Brown rice	0.08	0.93	0.80
Degermed brown rice	0.07	0.50	0.68
Germ	0.20	12.80	6.91
Milled rice a/	0.08	0.02	0.23
Parboiled: b/			
Brown rice	0.22	0.66	0.83
Milled rice a/	0.19	0.65	0.80

a/ Milled to 'full polish' (about 9-10% d.m. in raw and 7-8% in parboiled rice)

b/ Paddy soaked at 60° for 5.5 hr (optimum), steamed for 10 min at 0 psig

present in very high amounts in the germ, and in fairly high amounts in whole and degermed brown rice; they were drastically

reduced after milling. These data showed that the above components were largely concentrated in the germ and partly in the bran layers. Reducing sugars on the other hand were more evenly distributed in the grain. These data are broadly in accord with the results reviewed by BARBER (1972). Parboiled brown rice contained considerably more reducing sugar but less sucrose when compared to raw brown rice, suggesting some possible interconversion. Parboiled milled rice contained almost the same quantities of sugars and amino acids as in parboiled brown rice. This suggested that these constituents were possibly redistributed in the kernel during parboiling (like the B-vitamins) and hence were not appreciably lost during milling.

Chromatographic data were in general agreement with the above picture. The principal sugar in raw brown rice extract was sucrose; appreciable quantities of raffinose, another nonreducing sugar, were also present; small amounts of glucose and traces of fructose formed the reducing sugars of the grain. Chromatograms of degermed brown rice extract showed a similar picture but the quantities were less. Germ, on the other hand, contained very high amounts of sucrose and considerable quantities of raffinose.

Effect of progressive milling on the contents of sugars in raw and parboiled rice are shown in Fig. 31. The results clearly indicate the sharp decrease of sucrose content with progressive milling of raw rice whereas parboiling rendered a remarkable protection against such loss. Reducing sugars

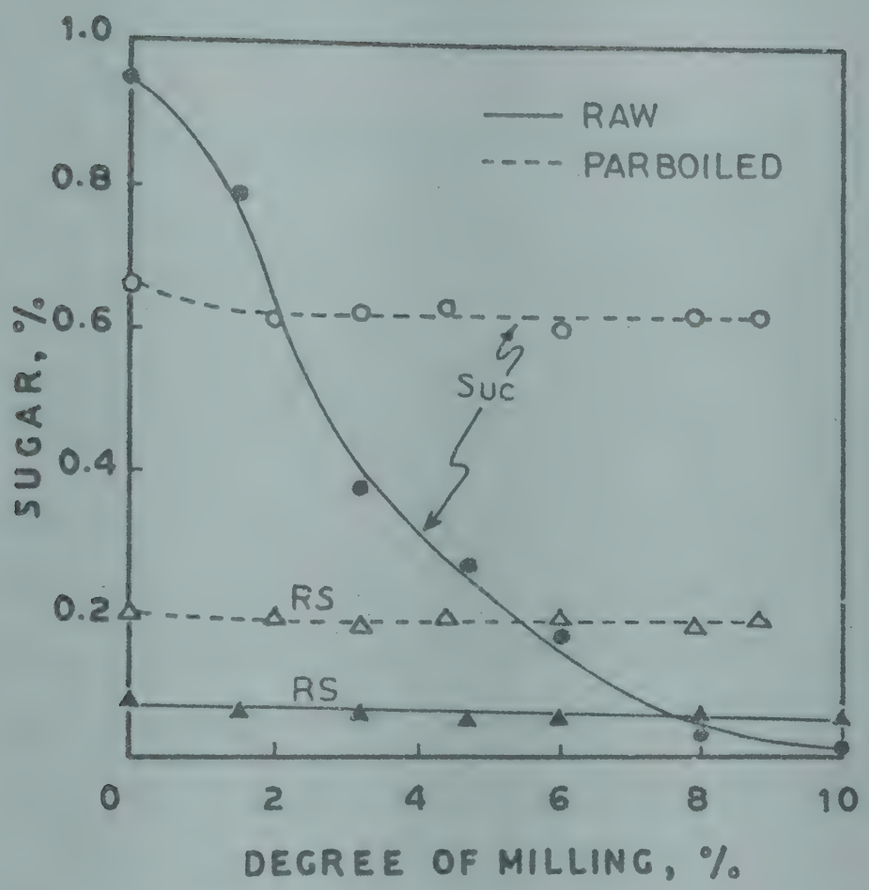


Fig. 31. Effect of progressive milling on sucrose and reducing sugar content of raw and parboiled rice.

(Parboiling: paddy soaked at 65° for 5.5 hr, steamed 10 min.
Suc, sucrose; RS, reducing sugars.)

showed little decrease during milling in either case, indicating their relatively uniform distribution in the kernel.

3.2. Effect of Different Processing Conditions on Sugars and Free Amino Acids

The effect of various processing conditions on the contents of sugars and amino acids in parboiled rice was studied. A wide range of parboiled rice samples was prepared by soaking paddy at three different temperatures (37°, 60° and 80°) for three different periods each (undersoaked, optimally soaked and oversoaked). Steaming was done for 10 min at atmospheric pressure. To study the effects of soaking, steaming and milling separately, both brown rice and fully milled rice obtained from both merely soaked and soaked and steamed (i.e. parboiled) paddy in each were analysed. The overall results are presented in Fig. 32.

Contents of sugars and amino acids in brown rice obtained from paddy after different conditions of soaking are reproduced in Fig. 33. Obviously considerable changes occurred in the grain during the process of soaking. In general, there was an increase in the RS and a decrease in sucrose content with progressive soaking. These changes were particularly pronounced at 60°C. The decrease in sucrose was, however, much greater compared to the increase in reducing sugars, indicating its loss either due to metabolic processes or leaching. FAA showed relatively less change.

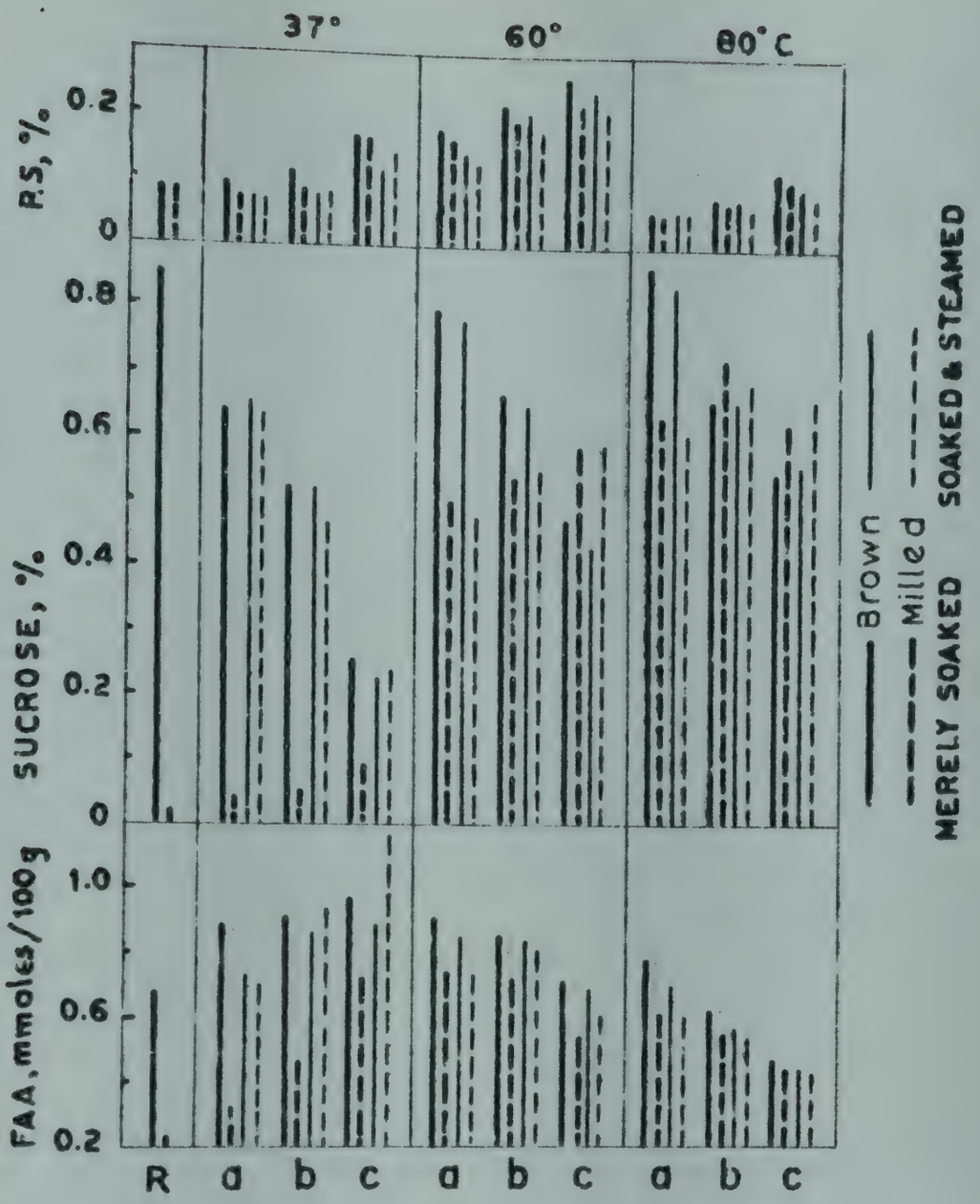


Fig. 32. Effect of soaking, steaming and milling of paddy on contents of sugars and free amino acids.

(Paddy soaked at 37°, 60° and 80°C for under (a), optimal (b) and over soaking (c) periods each. Half of soaked paddy dried, shelled (brown rice) and milled (milled rice) as such. Other half steamed and then dried, shelled and milled. Original raw (R) brown and milled rice shown at extreme left.)

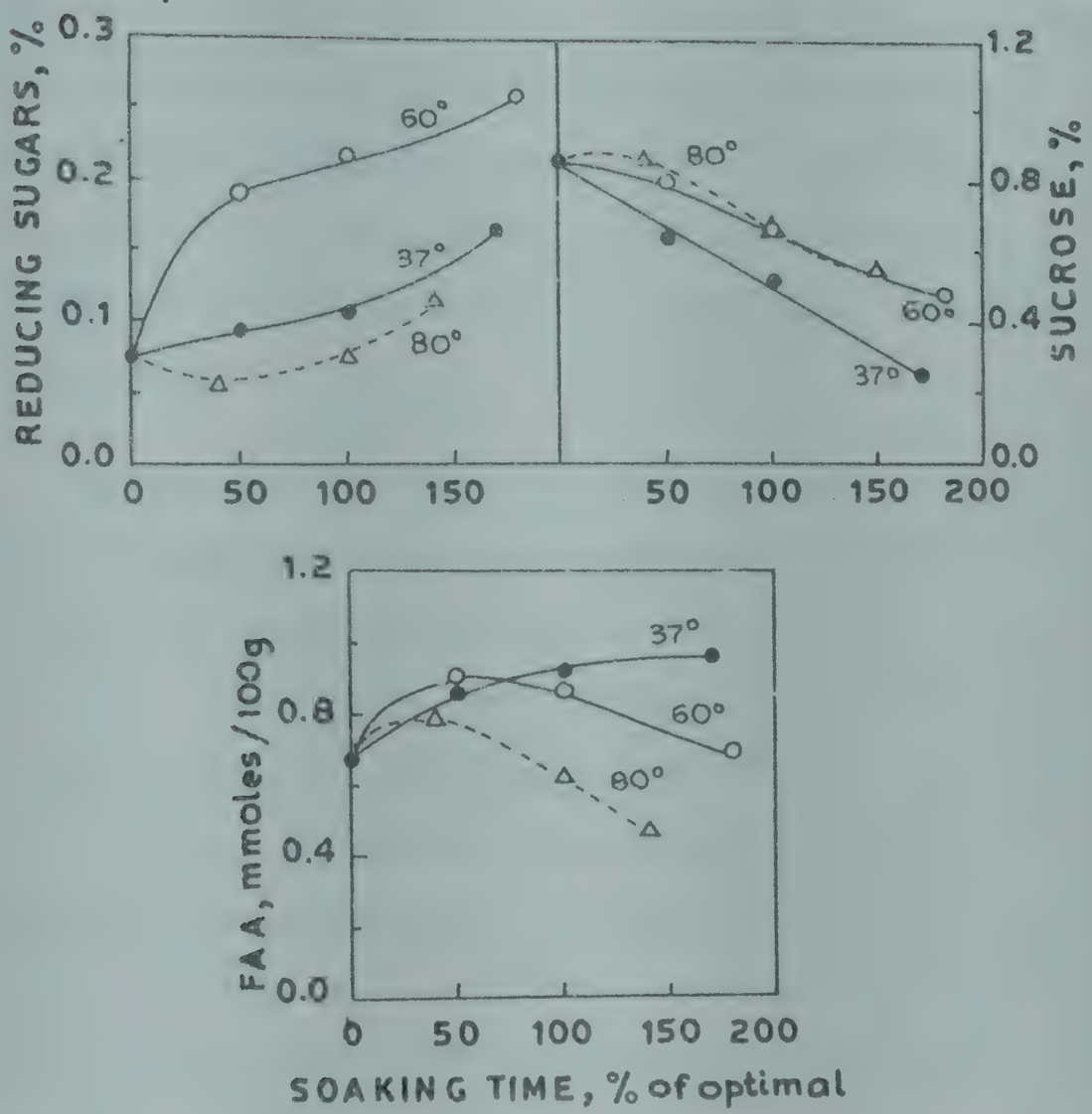


Fig. 33. Effect of temperature and time of soaking of paddy on sugars and free amino acids of resulting brown rice.

(Optimal soaking time: 30 hr at 37°, 5 hr at 60°, 2.5 hr at 80°C. Temperature of soaking, °C, as indicated.)

Effect of steaming could be seen by comparing the above results with those of brown rice obtained after the paddy samples had been steamed (Fig. 32). Steaming tended to lower the reducing sugar content after soaking at low temperatures but not significantly after soaking at 80°C. Free amino acids too followed a more or less similar trend, suggesting the involvement of RS and FAA in Maillard type reaction. Sucrose was little affected.

Coming to the effect of milling, brown rice obtained from paddy merely soaked at 37° behaved just like raw rice, while that from paddy merely soaked at 80°C behaved like parboiled rice. Thus there was considerable loss of sucrose and FAA during milling of the former, but not from the latter. Samples soaked at 60° showed an intermediate behaviour. RS was affected but little in any sample, as already expected (see Table 17, Fig. 31). Milling after full parboiling (soaking and steaming) gave only minor changes in the constituents in all cases.

3.3. Incubation Experiments

Incubation studies were carried out to better understand the changes occurring in paddy grain during soaking.

3.3.1. Incubation of rice powder: Rice flour from raw brown or milled rice (10.2% d.m.) in water was first incubated at different temperatures (25°-80°C) for 1 hr. It was observed (Fig. 34) that brown rice showed two temperature

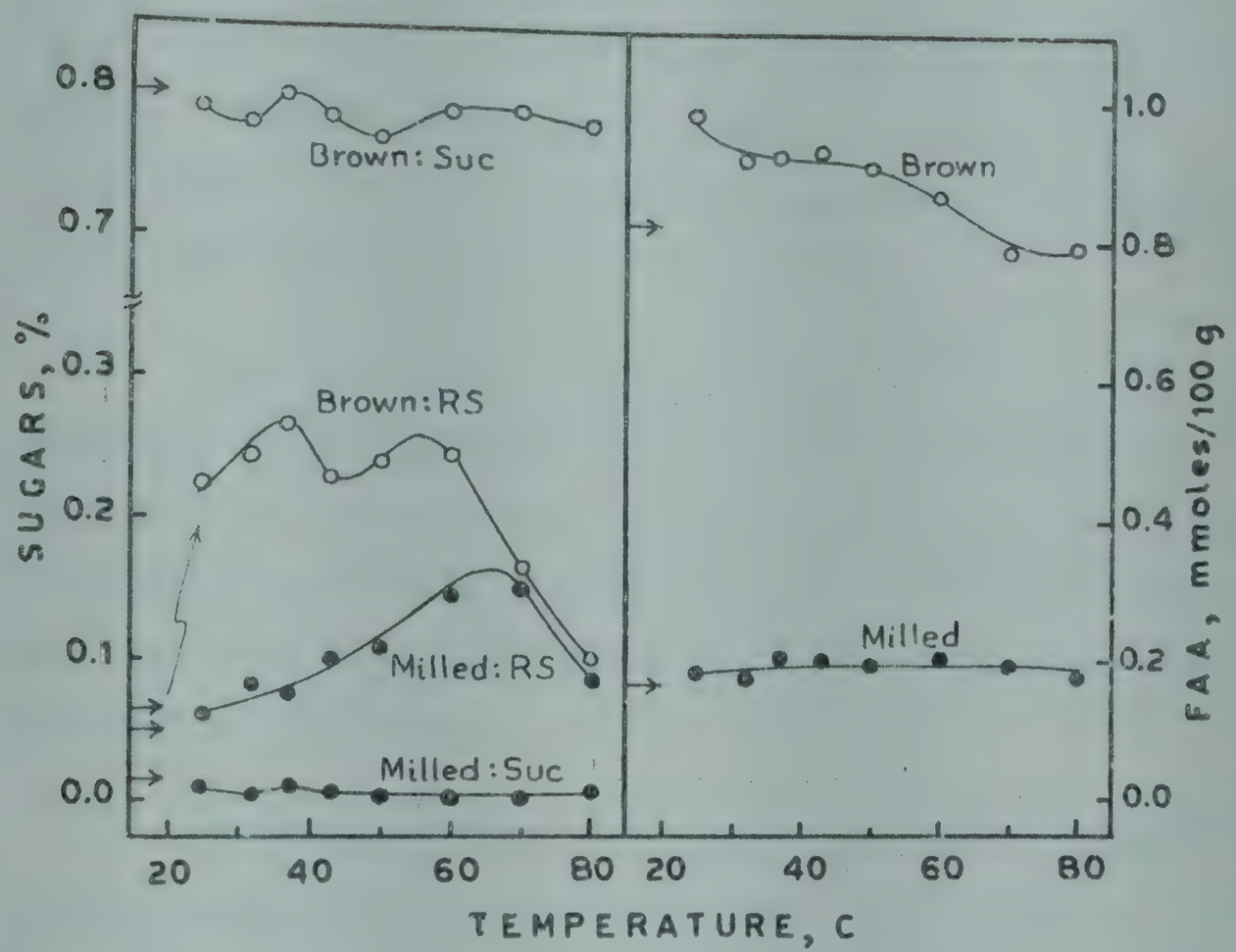


Fig. 34. Effect of incubating brown rice and milled rice powder in water at different temperatures on the content of sugars and free amino acids.

(Incubated for 1 hr. The arrows indicate the respective contents in the original unincubated rice.)

peaks (37° and 60°C) of release of RS. In milled rice, the peak at 37° was absent. This suggested the existence of two enzyme systems having different temperature optima in the grain, the one with optimum at 37°C being present only in the outer layers. Sucrose showed little change, unlike as seen earlier. FAA in brown rice showed a moderate increase at low temperatures, but little or no change after 70°C.

When brown rice powder was incubated upto 24 hr, the release of RS was greater at 37° and RT than at 55°C (Fig. 35). FAA followed an essentially similar trend. Sucrose content decreased concurrently, but the increase in reducing sugars was very much higher than the decrease in sucrose content (in contrast to Fig. 33).

Chromatography of the extracts of these incubation studies supported the above findings. In addition it showed the presence of traces of melibiose. The greater increase in RS than decrease in sucrose was confirmed. Also, glucose was produced to a greater extent than fructose. These two findings suggested that a part of the RS was produced from sources other than sucrose. Traces of maltose were also observed after incubation. Extra maltose added during incubation showed a decrease, indicating the presence of the enzyme maltase.

3.3.2. Incubation of raw brown rice, degermed brown rice and excised embryo: In view of the somewhat unusual results with rice powder, and since the organized grain

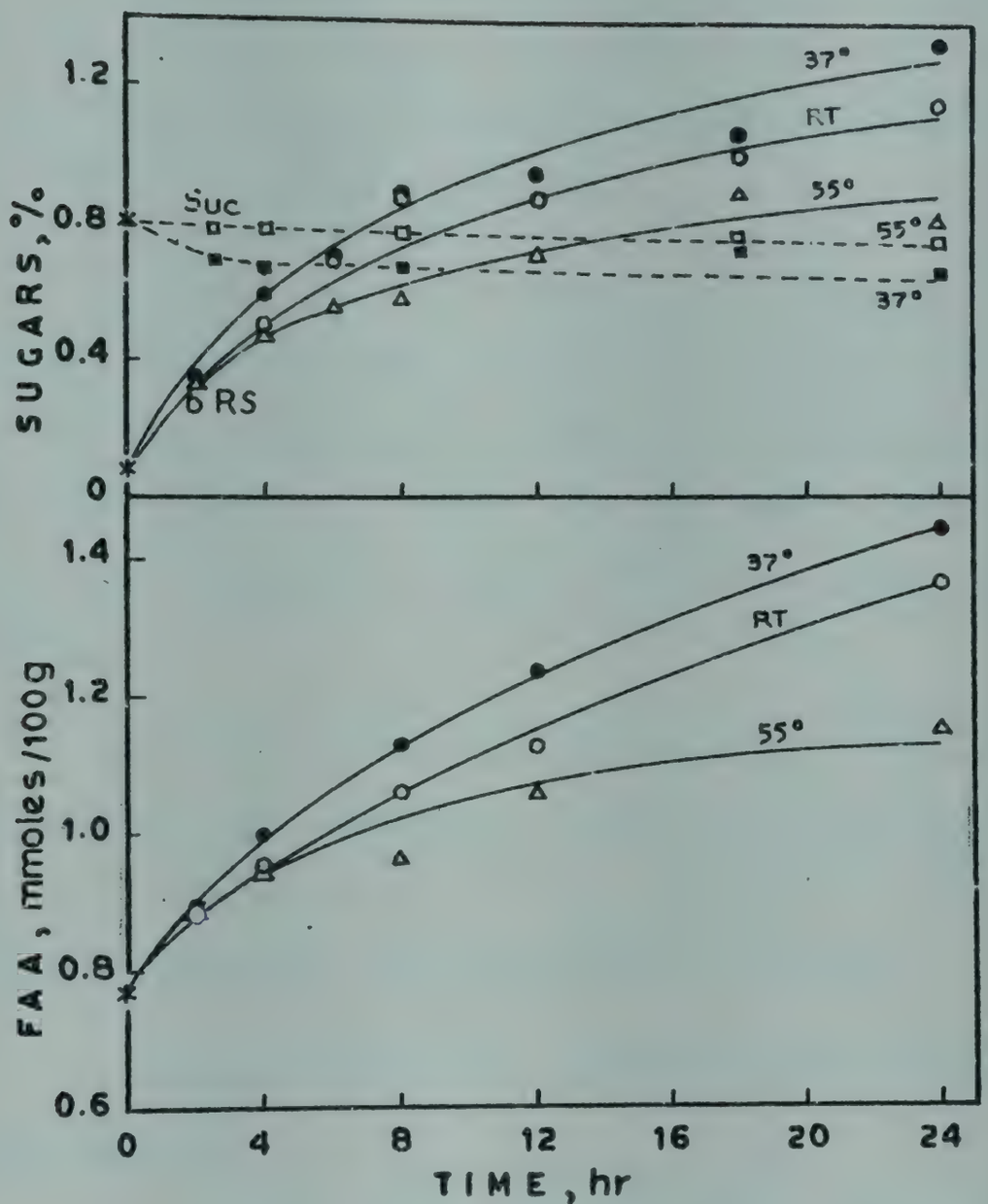


Fig. 35. Effect of incubating raw brown rice powder in water at different temperatures on the contents of sugars and free amino acids.

structure was disrupted after grinding, subsequent incubation studies were undertaken with whole brown rice, degermed brown rice and excised embryo. To simulate the conditions of high-temperature soaking, incubation at 80°C was also included. The results are presented in Fig. 36.

Maximum changes in sugars were observed at 55° followed by 37°C in case of intact and degermed brown rice, (in agreement with Fig. 33), whereas the reverse was the case for excised embryo (in which case the results were similar to those with brown rice powder). There was little or no change at 80°C.

In whole brown rice, the increase in RS was slightly greater than the decrease in sucrose (again contrast to Fig. 33). Chromatograms of the extracts also gave a similar picture. However, raffinose showed no change.

Degermed brown rice showed similar changes but to a lesser extent.

Incubation of excised germ gave a picture broadly similar to that of brown rice powder. However, unlike in the latter case, the increase in RS was more or less balanced by the decrease in sucrose content here. Chromatographic studies confirmed this further.

Free amino acids in the above studies did not give a definite pattern. However, there appeared to be a rapid increase followed by a decrease in the first few hours, and

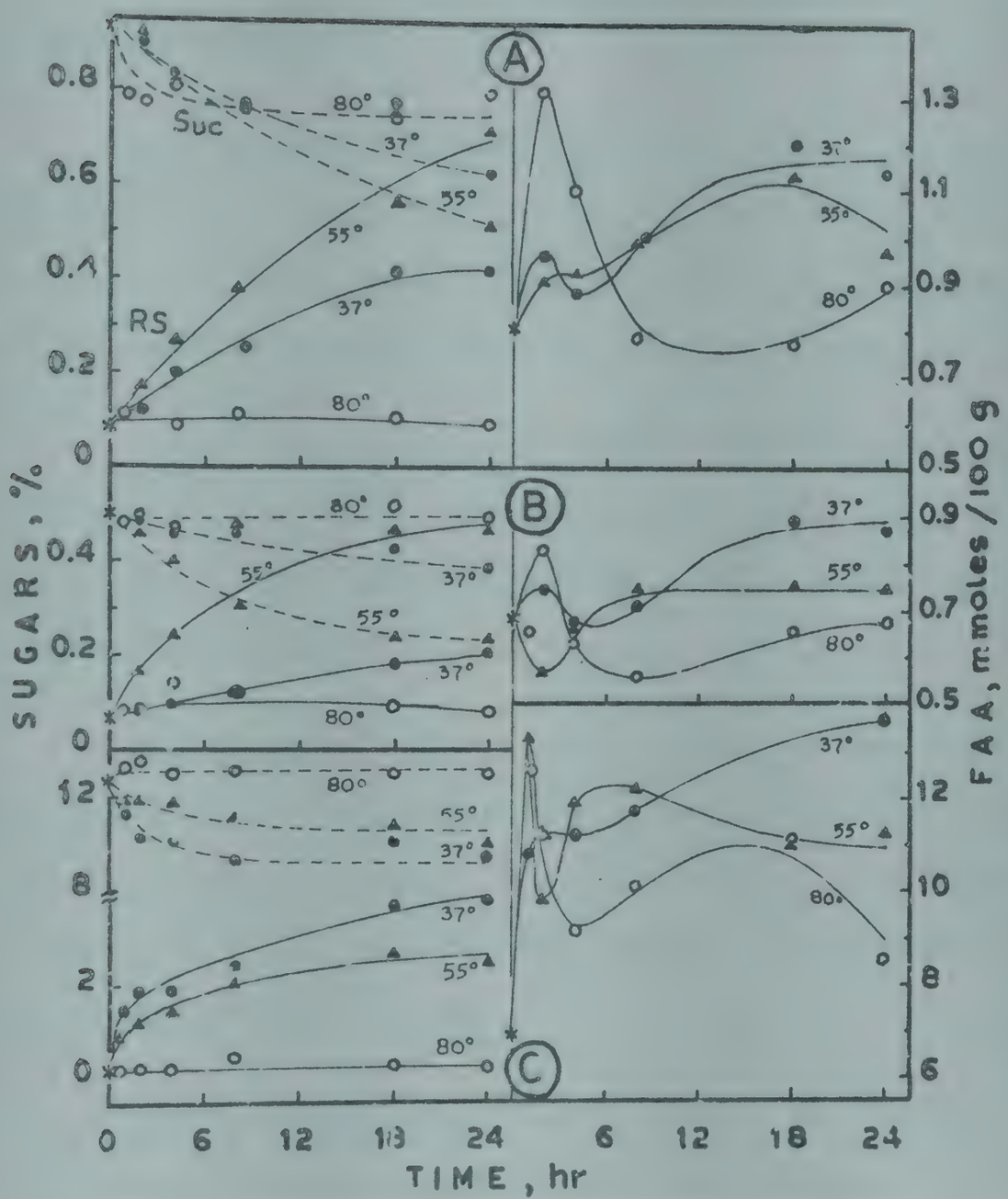


Fig. 36. Effect of incubating whole brown rice (A), degermed brown rice (B), and excised embryo (C) in water at different temperatures on the content of sugars and free amino acids.

then a slow change afterwards at all temperatures. Changes were more pronounced in the embryo followed by whole kernel and degermed brown rice; they decreased with increasing temperature of incubation.

All the above incubation studies were carried out by using highly viable grains (> 95% germination). Another set of experiments with paddy which had lost its viability gave somewhat erratic but on the whole similar results.

3.3.3. Incubation of paddy: To simulate natural conditions more closely, incubation of paddy itself was then carried out. Only 37° was studied in this case. The results are presented in Fig. 37.

The trend of changes was similar to that observed in other cases, i.e. an increase in RS and decrease in sucrose. But in this case, the rate of change seemed to be faster than observed with brown rice and the decrease in sucrose nearly balanced the increase in RS.

Loss of sugars due to leaching: The values of sugars in the above experiment were much higher compared to those observed in parboiled rice. This indicated that during soaking of paddy a good part of the sugars might be leaching out into the soak water (which is discarded).

To test the above point, paddy and brown rice kernels were incubated at 37°C as above but the sugars were analysed separately in the kernel and the water, at the end of 24 and 48 hr. The results are presented in the Table 18.

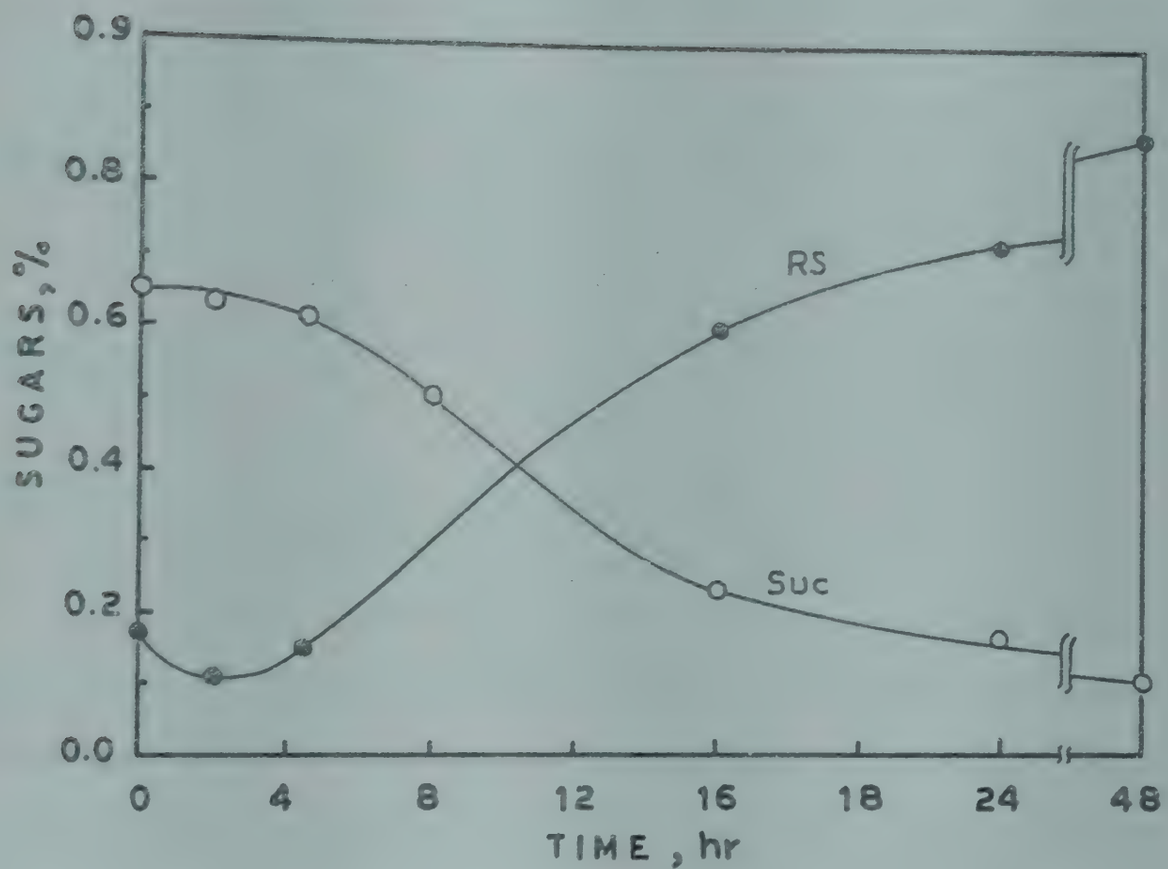


Fig. 37. Effect of incubating paddy in water at 37°C on reducing sugars and sucrose content.

Table 18

Leaching of sugars during soaking of paddy (37°C)

Material	Incubation period (hr)	Reducing sugars		Sucrose	
		Total (grain + soak water), % of rice	% of total in soak water	Total (grain + soak water), % of rice	% of total in soak water
Paddy	0	0.20	--	0.75	--
	24	0.58	51.5	0.33	39.0
	48	0.88	79.4	0.10	71.8
Brown rice	24	0.83	88.5	0.43	89.0
	48	1.22	82.2	0.21	100.0

It is clear that although there was considerable increase in RS and a simultaneous and more or less equivalent decrease in the sucrose content during incubation, the greater part of the sugars was leached out into the soak water. About half of the sugars at the end of 24 hr and three-fourths at the end of 48 hr were found to have been leached out in the soak water. The leaching was much greater in brown rice, as expected.

4.0. DISCUSSION

While it is difficult to interprete all the above results, they clearly confirm the occurrence of enzymic changes in sugars and amino acids in paddy grain during soaking for parboiling. This is not surprising, since the soaking step simulates the initial stage of germination when a host of

metabolic processes becomes active in the grain. The major change in sugars seems to consist of conversion of a part of sucrose to reducing sugars. Some free amino acids are also produced.

The main point of interest for the present purpose is that production of reducing sugar in the intact grain increased with increasing temperature upto about 60°C (Figs. 33 and 36). This would undoubtedly have some impact on the quality of the product inasmuch as reducing sugars are involved in browning reaction. The findings of BHATTACHARYA (CFTRI, unpublished) that discolouration observed upon heating of milled parboiled rice increased with increasing soaking temperature of paddy upto about 60° and then decreased, are in accord with the above findings.

The other point of importance is the loss of sugars during soaking by leaching. About 0.5% of the grain weight was thus lost after soaking for 24 hr at 37°C, and more after more time. This is when fermentation was kept under check. Clearly this is an important source of dry matter loss during soaking and might be the main factor supporting microbial fermentation in traditional parboiling.

The present results also suggest that the greater retention of B vitamins in milled parboiled rice is not something unique. Sugars and amino acids are also similarly retained. However, the same data also show that the greater

retention is not due necessarily to increased migration of water-soluble constituents during soaking and steaming, as is generally thought. In fact, a good part of the sugars migrated outwards and were leached out during soaking. Clearly, the protection against milling loss arose from some form of fixation caused by the gelatinization of starch, as has been also suggested in the case of B-vitamins by SUBBA RAO & BHATTACHARYA (1966).

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Chapter XI

GENERAL DISCUSSION

Although the nutritional aspects of parboiled rice and the technological aspects of the parboiling process have received considerable research attention, not much work was done in the past to understand the changes that take place in the rice grain as a result of parboiling. A growing recognition of this fact seems to have emerged during recent years and, of late, studies relating to the changes are coming forth. However, a comprehensive picture did not yet emerge which could give a clear understanding of the nature of parboiled rice and explain its peculiar properties, e.g. the long time it needs to cook despite being pregelatinized.

Nature of Parboiled Rice

The present work has thrown considerable light on the fundamental changes during parboiling and on the underlying basis of the characteristic properties of parboiled and allied rice products. Its hydration and other properties, viewed in contrast to the same properties of its foil, viz. parboiled rice produced by sand roasting, leave no doubt that the properties of normal parboiled rice is the sum-total of starch gelatinization on the one hand and some sort of a starch reassociation or retrogradation on the other.

The influence of gelatinization is obvious from the effects of various processing conditions, when any condition that favoured gelatinization (mere soaking of paddy above 70°C, or soaking at any temperature followed by steaming) immediately changed the hydration and other properties of the resulting rice. Even the protection to rice sugars against milling loss (Chapter X) followed the same pattern. As earlier work has shown, improvement in milling quality, discolouration of rice, resistance to rice cracking when soaked in water, and retention of B vitamins after milling too were influenced precisely in the same manner (BHATTACHARYA & SUBBA RAO 1966a, 1966b, SUBBA RAO & BHATTACHARYA 1966). Besides, RAGHAVENDRA RAO & JULIANO (1970) have provided direct evidence of starch gelatinization in parboiled rice.

However, starch gelatinization alone cannot explain the characteristic properties of the product. Here, the peculiar inversion in its hydration, amylose-solubility and alkali-reactivity behaviour depending on the temperature and alkali strength, its characteristic pasting behaviour and digestion by glucoamylase, and above all the dramatic fall in its hydration power during storage or drying following steaming, leave no doubt that there occurs some sort of starch reassociation or retrogradation in parboiled rice following gelatinization. This conclusion is all the more reinforced by the contrasting properties of parboiled rice produced by sand roasting, where it became evident that the quick

dehydration during roasting prevents similar starch reassociation in this product. Another product derived from the latter, flaked rice, behaved similarly but with still greater cold-swelling behaviour apparently because of starch damage during flaking.

The enzymic changes in sugars and amino acids in the grain during soaking and the effect of gelatinization in protecting these constituents from being lost during milling also undoubtedly contribute in a minor way to the quality of the final product. Other studies showing the changes in proteins and fats and in morphological characters which also contribute to some minor characteristics of parboiled rice have already been pointed out earlier (Chapter I).

In a very recent work taken up much after the present work was initiated, PRIESTLEY (1976a, 1976b, 1977) has also independently proposed a hypothesis about the fundamental nature of parboiled rice, which is in essence not dissimilar to the one proposed here. He studied mainly the X-ray diffraction pattern and the dispersible solids of rice. He observed that the X-ray diffraction pattern of rice changed after parboiling from the A to the V type, from which he proposed that the amylose was converted to an insoluble helical complex, perhaps with fatty acids. He also discounted the possibility of any starch retrogradation in parboiled rice as he did not observe any characteristic peak in its

X-ray diffraction curve, but suggested that the above insolubilization of amylose was responsible for the properties of parboiled rice.

The following points need to be considered in this context: (a) Even assuming that there is no major starch retrogradation in parboiled rice, at least a part of the amylose must be retrograded in situ as always happens upon cooking of starch (SCHOCH & FRENCH 1947). It is therefore surprising that no peak corresponding to retrograded starch was seen in the diffractogram at all. PRIESTLEY's diffraction data therefore might need to be reexamined. (b) The starch retrogradation suggested here might well represent relatively weak associations between the outer chains of amylopectin, as has also been suggested in the case of staling of bread (MAGA 1975). In that case, these weak bonds might not be reflected in the X-ray curve. (c) PRIESTLEY (1976b, 1977) himself noticed that the dispersible solids of rice (obtained after homogenization by sonic vibration) was more in severe than in mild parboiled rice immediately after steaming, but was the reverse after the paddy was dried, milled and recooked.* It would be difficult to explain this result on the basis of his hypothesis of partial insolubilization of the amylose alone; more extensive starch reassociation throughout the granule must be assumed. (d) Finally, in

* Incidentally, this result is very similar to the drop in EMC -S of parboiled paddy during storage or drying after steaming, as observed here.

any case, the problem might be semantic. The present as well as PRIESTLEY's data leave no doubt whatsoever that some sort of reassociation or insolubilization of starch occurs throughout the granule (and not just in the amylose molecules) upon parboiling of rice, which is what confers it its unique properties. What precise type of reassociation this is and what precise bondings are involved, is a subject that may need further specific studies.

Unified Theory of Precooked Rice (and Other Starch) Products

A unified understanding about the nature of precooked rice and other starch products in general can be gained from the present studies. As rice (and perhaps other cereals and starchy foods) is cooked, the starch is gelatinized. If the material is then dried for later use, a part of the gelatinized starch would be reassociated depending on the circumstances of its drying and storage. If the drying is nearly instantaneous -- as in parboiled rice produced by sand roasting, or when a starch slurry is simultaneously cooked and dried by drum drying --, the reassociation would be minimal and the product would show good cold-swelling behaviour. When on the other hand the drying is slow -- as in normal steam-parboiled rice --, or if the wet cooked product is stored in cold, there would be appreciable starch retrogradation and the product would be relatively hard to recook. Many quick-cooking rice (and other cereal) products

are deliberately dried in such a way as to leave many fissures, to facilitate entry of water, to overcome this difficulty (ROBERTS 1972).

Further change occurs if the wet cooked product is flaked or 'bumped' -- as in flaked rice or other cereals. This flaking seems to cause starch damage which, if the product is already dry or is quickly dried, increases its quick-cooking and cold-swelling property. This (apart from increasing the surface area per unit weight, which increases the cooking rate) seems to be the basis of the quick-cooking behaviour of flaked rice and other cereals. Even puffed rice (and maize) probably belong to this category. The sudden enormous expansion under pressure seems to cause extensive starch damage which, in the absence of subsequent retrogradation because of the product being dry, yields a quick-cooking product even though it was never initially cooked in the true sense. Similarly the special benefits conferred by wet grinding in the preparation of many snack foods could be associated with such starch damage.

Tests for Parboiled Rice and for the Degree of Parboiling

No simple and effective test for parboiled rice was known so far. The slower cooking rate of parboiled rice at boiling temperature (SANJIVA RAO 1948, KURIEN et al 1964, BHATTACHARYA & SUBBA RAO 1966b), its enhanced colour (JOHNSON 1965, STERMER 1968), the relative insolubility of its protein (DIMPOPOULOS & MULLER 1972), and its expansion upon heating

(ROBERTS et al 1954) have been suggested earlier as bases for tests; but these were not further developed. The present work has provided several simple, elegant and specific tests to distinguish parboiled from raw rice as well for the degree of parboiling, as listed below:

(a) Since the water uptake of rice at 60° and 96°C increases and decreases, respectively, on parboiling, proportional to its severity, these values, and more particularly their ratio (W_{60}/W_{96}), provide excellent tests for parboiled rice and its severity. For instance the value of this ratio was about 5% for raw rice and rose to about 50% for severely parboiled rice.

(b) The EMC-S of rice provided another extremely simple and effective test. Thus its value was about 28% moisture (wet basis) for raw rice and went upto about 50% moisture for severely parboiled rice. In addition, by following the EMC-S of a product at different time intervals after cooking, or after different steps of processing, one can follow the progress of gelatinization and/or starch retrogradation in it. In this sense, the EMC-S test can be a powerful tool in starch research.

(c) Similarly the water-soluble amylose content of rice at 50° and 96°C, and more particularly their ratio (sA_{50}/sA_{96}), provided good tests for parboiled rice and its

severity. This test is similar to the well-known WILLIAMS & FEGOL (1969) test for starch damage in wheat flour.

(d) Another elegant and very rapid test is the alkali test. By putting a few rice kernels in very dilute alkali, one can readily distinguish between raw and various degrees of parboiled rice.

(e) Since parboiled rice, and in particular roasted and flaked rice, showed a measurable viscosity of their cold slurry, this also can be employed as a useful test particularly for less retrograded rice (and starch) products. This test is akin to the well-known MacMichael viscosity test of wheat flour for starch damage and protein quality (PRATT 1971).

(f) The sedimentation volume of the cold slurry is another elegant test particularly for less retrograded rice (and starch) products. This test is somewhat similar to the well-known Zeleny sedimentation test of wheat for protein quality (ZELENY 1971).

It is clear from the present work that the properties of parboiled rice, and for that matter of any precooked starchy product, is a net reflection of the extent of starch gelatinization on the one hand and of the extent of its reassociation on the other. Separate determination of these two changes is therefore necessary for a complete characterization of the product. Attempts at individual determination

of gelatinization and retrogradation in parboiled rice were not successful here. This is clearly an important task for the future.

Practical Implications

The present results have also important practical implications.

Firstly, since these results provide a fairly comprehensive theory about the nature of precooked products prepared under various conditions, this understanding will help in the future modification and development of products to suit diverse requirements.

Secondly, these results may help in the development of newer forms of parboiled rice in particular, with more desirable consumer quality. If parboiled rice is produced by a high temperature-short time technique so that the product is simultaneously dried while being gelatinized, the resulting rice will have better consumer acceptance in view of less time and cost of cooking.

Thirdly, having understood the fundamental nature of parboiled rice, if simple ways are found to reverse the associative bonds, this will also help in reducing the time and cost of cooking. These will help in popularisation of parboiled rice.

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SUMMARY

1. The present studies were planned with the aim of elucidating the fundamental nature of parboiled rice and the basis of some of its known properties. Parboiled rice was prepared under varied processing conditions to give very mild to severely parboiled rice. Its various properties were studied in comparison to raw rice. Certain other products essentially similar to parboiled rice in terms of processing conditions but different in their properties (viz., parboiled rice produced by quick sand roasting and flaked rice) were also included in the study to throw more light on the subject by comparison.

2. It is known that parboiled rice, even though a precooked product, needs a longer time to cook than raw rice. However a detailed study of its hydration at different temperatures showed that the behaviour was much more complex. When cooked at the boiling temperature, raw rice no doubt hydrated more than parboiled rice. But at low temperatures the situation was just the reverse and parboiled rice now hydrated faster and to a greater extent than raw rice. The difference between raw and parboiled rice at both the temperatures increased with increasing severity of parboiling.

There was a transition temperature (near the gelatinization temperature, about 80°) at which all the samples hydrated more or less equally. The farther the cooking temperature was from this transition temperature, the greater was the difference in water uptake among the various samples.

Values of water uptake at 60° and 96°, and more particularly their ratio (W_{60}/W_{96}), therefore gave excellent tests of parboiled rice and its severity. Thus the value of the ratio was about 5% for raw rice and rose to about 50% for severely parboiled rice.

3. The equilibrium moisture content attained by rice upon soaking in water at room temperature (EMC-S), in keeping with the higher hydration power of parboiled rice at low temperatures, was higher in parboiled than in raw rice and increased with the increasing severity of parboiling. For instance, the value was approximately 28% moisture (wet basis) for raw rice and went upto about 50% moisture for severely parboiled rice. This value also therefore gave a very simple and effective test of parboiled rice and of the degree of parboiling.

4. The water solubility of the amylose content of rice again largely followed the hydration pattern. The solubility of amylose was more or less identical in raw and parboiled rice at about 80°C. Above this temperature, the solubility was the highest in raw and least in severely

parboiled rice; but below this temperature, severely parboiled rice gave the highest soluble amylose. The values of soluble amylose at 50° and 96°, and their ratio (sA_{50}/sA_{96}), therefore again gave good indices of parboiled rice and of the degree of parboiling.

The sA_{50} and sA_{96} values were linearly related to W_{60} and W_{96} values, respectively.

5. Reaction of parboiled rice in dilute alkali differed in many respects from that of raw rice. Parboiled kernels were attacked much sooner by alkali than raw kernels; they did not show any cracking and corrosion characteristic of raw kernels but were simply swollen and degraded; and they showed very little collar. Most importantly, they were attacked and degraded by such dilute alkali as would not attack the corresponding raw kernels at all; and the extent of degradation increased with increasing severity of parboiling. Reaction in such dilute alkali therefore readily distinguished raw from parboiled rice as well as the severity of parboiling.

In moderate alkali solutions, on the other hand, raw rice seemed to be degraded a little more than parboiled rice. Thus this behaviour too was somewhat reminiscent of the hydration and amylose-solubility patterns.

6. Parboiling produced significant changes in the pasting behaviour of rice as studied using a Brabender viscograph. At a fixed slurry concentration, the peak viscosity (P), breakdown (BD) and setback (SB) decreased, while the temperature of the initial rise in viscosity (the 'gelatinization temperature') increased as a result of parboiling. When compared at a fixed P value, the BD again decreased but the SB increased. These effects were proportional to the severity of parboiling.

Since these differences did not provide a clear picture, the samples were viscographed at several slurry concentrations each and the plots of their resulting viscosity values against concentration in log-log coordinates were compared. It was immediately evident that the viscograms were essentially similar in all samples. The only difference was that the lowest peak viscosity at which a measurable breakdown first appeared was pushed towards higher viscosity values and concentrations in parboiled rice, proportional to its severity, as compared to raw rice. This suggested a decreased swelling ability of the granules in parboiled rice compared to raw rice.

7. Taken together, the above behaviours suggested that a part of the gelatinized starch in parboiled rice probably undergoes some reassociation or retrogradation later. Thus the residual unassociated gelatinized starch in it would

account for the faster hydration and greater amylose solubility at low temperatures as well as easy degradation by very dilute alkali. At high temperatures, on the other hand, the retrograded portion of the starch in parboiled rice would resist hydration and solubilization and hence raw rice (which is being readily and fully gelatinized at the high temperature) is now hydrated and solubilized faster than parboiled rice. The decreased swelling ability of starch granules in the parboiled rice slurry (as seen in the viscograph) could also be due to the same reason.

8. For producing flaked rice, soaked paddy is quickly roasted by sand and then flattened. Rice milled from the intermediate product, roasted paddy, is nothing but a kind of parboiled rice, but it behaved rather differently. While in every property it behaved like severe or very severe parboiled rice (very high EMC-S, W_{60}, sA_{50}, alkali degradation), its W_{96} value did not show a proportionate drop characteristic of normal parboiled rice. Flaked rice behaved similarly but in a still more exaggerated way. Roasted and flaked rice, the latter in particular, also showed a distinct cold-swelling behaviour not shown by normal parboiled rice. Thus when these products were powdered and mixed with water, the cold slurry showed a perceptible viscosity and also a high sediment volume. The hydration power, viscosity and sediment volume were mutually related.

9. The above contrary properties of roasted and flaked rice on the one hand and normal parboiled rice on the other, supported the hypothesis of starch retrogradation in normal parboiled rice. It appeared that the rapid and simultaneous dehydration during gelatinization by sand roasting prevented starch reassociation in roasted rice and therefore imparted in it a high hydration and cold-swelling power. The still greater hydration power of flaked rice could be due to some further change occurring during the flaking step.

In normal steam-parboiled rice, on the other hand, the high moisture content in the gelatinized product probably favoured starch reassociation and gave it its characteristic properties. In support, it was noticed that digestion with glucoamylase led to a lower release of glucose from parboiled rice, proportional to its severity, as compared to from raw rice.

10. To verify the above hypothesis, hydration power of parboiled paddy was followed at different time intervals right from the moment of its steaming. It was observed that the equilibrium moisture content attained on soaking in water (EMC-S) of parboiled paddy was unusually high when determined immediately after steaming. The value fell progressively and markedly on storage or on slow drying, ending after a few hours in the familiar range encountered in milled parboiled rice. This reduction in hydration ability clearly demonstrated the gradual retrogradation of the starch in parboiled rice following its cooking.

The extent of retrogradation (i.e., the drop in hydration power upon storage) was dependent on the moisture content of the paddy. Too high as well as too low moisture contents reduced the retrogradation. Similarly, quick drying of parboiled paddy reduced the extent of retrogradation in the finished rice.

The retrogradation was also dependent on the temperature of storage of the paddy. Thus the retrogradation was maximum at a definite moisture, but this optimum moisture content itself varied inversely with the temperature of storage. The optimum was at about 25% moisture for storage at room temperature, at about 30% moisture for 8° storage and at about 20% moisture for 70°C storage. Also, preformed retrogradation could be reversed by heating in presence of relatively high moisture content.

11. Laboratory studies with roasted and flaked rice were carried out in the above lines to account for their properties. Roasting of soaked raw paddy in hot sand raised its EMC-S due to gelatinization, proportional to the temperature and duration of roasting. Flaking of the roasted paddy raised the EMC-S further. When samples were roasted down to different moisture contents (13-23%) and stored, there was no drop in hydration ability of those samples which had less than 18% moisture for room-temperature storage, and less than 12% moisture for 70° storage. Samples with higher moisture

showed increasing loss in hydration power (i.e. retrogradation). Similarly, retrogradation could be induced in dry roasted or flaked rice by increasing their moisture content (by adding water) appropriately.

These results confirmed that roasted rice was essentially not different from steam-parboiled rice. Its normally high hydration ability was due to the low moisture content of the product as normally produced, which prevented its retrogradation.

12. However, the above alone could not account for the still higher hydration power of flaked rice. It was observed that flaking of any of the products -- raw, parboiled, roasted; hot or cold -- raised its hydration power. This suggested that the starch underwent plastic deformation during flaking, causing mechanical damage to the granules, which led to its increased hydration capacity.

13. Parboiled brown rice contained considerably more reducing sugars (RS) but somewhat less sucrose and free amino acids (FAA) than raw brown rice. On milling, there was considerable loss of sucrose and FAA from raw rice, but very little from parboiled rice. Reducing sugars changed little on milling both in raw and parboiled rice.

The processing conditions affected the contents of sugar and FAA in parboiled rice. Maximum increase in RS

(and decrease in sucrose) occurred after soaking at 60°, less at 37° and very little at 80°C.

Considerable changes in sugars and FAA occurred upon incubation of brown rice powder, whole brown rice, degermed brown rice, excised embryo and paddy in water. In all cases RS and FAA increased and sucrose decreased at 37° and 55°, though the pattern and magnitude differed among the samples, while there was very little change at 80°C. Production of RS was far in excess of the loss in sucrose in brown rice powder, but the two were nearly balanced in unground material.

Analysis of grain and incubation medium separately after incubation showed that about 50% of the total sugars in the case of paddy and 80% in the case of brown rice leached out into the medium after 24 hr incubation at 37°C.

These data drew attention to the following: (a) Enzymic changes in sugars and amino acids occurred in the grain during soaking for parboiling, the magnitudes depending on the conditions. Such changes would undoubtedly affect the quality of the product, particularly with respect to the colour. (b) Significant loss of dry matter of the paddy grain (at least 0.5%) occurred during its soaking in the form of leaching out of sugars. (c) Parboiling (i.e. gelatinization) conferred considerable protection to residual rice sugars against milling loss (like B vitamins).

14. Effect of processing conditions during parboiling on the product quality was investigated with the test indices mentioned above.

Mere soaking of paddy upto temperatures of 60°C did not alter the various properties of rice (hydration ability, amylose solubility, susceptibility to degradation in alkali, etc). Higher temperatures of soaking, on the other hand, affected the properties. Thus mere soaking at 80° for optimal time produced the effect of mild parboiling, and over-soaking at this temperature produced quite severe parboiling. Mere soaking at 70° gave a pattern in between; while soaking for the optimal period did not produce any appreciable effect, over-soaking gave indications of incipient parboiling. Steaming following soaking immediately showed its effect, which was proportional to the severity of steaming. Even the retention of sugars against milling loss largely followed the above pattern.

These data showed that starch gelatinization was the key primary change in the parboiling process.

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REFERENCES

Abdul-Baki, A.A.
1969 Metabolism of barley seed during early hours of germination. Plant Physiol. 44:733.

Alary, R., Laignelet, B. and Feillet, P.
1977 Effects of amylose content on some characteristics of parboiled rice. J. Agr. Food Chem. 25:261.

Ali, N. and Ojha, T.P.
1976a Parboiling in 'Rice - Post Harvest Technology'. E.V. Araullo, D.B. de Padua and Michael Graham (eds), IDRC Canada, p.161.

Ali, N. and Ojha, T.P.
1976b Determination of optimum soaking conditions for parboiling of paddy. R.P.E.C. Reporter. 2(1):17.

Ali, N. and Ojha, T.P.
1976c Swelling of paddy during soaking. R.P.E.C. Reporter. 2(2):16.

Ali, N. and Ojha, T.P.
1977 Cooking quality of raw rice and parboiled rice. R.P.E.C. Reporter. 3(1):22.

Antonio, A.A. and Juliano, B.O.
1973 Amylose content and puffed volume of parboiled rice. J. Food Sci. 38:915.

Arai, K., Raghavendra Rao, S.N. and Desikachar, H.S.R.
1975 Studies on the effect of parboiling on japonica and indica rice. (in Japanese). Jap. J. Trop. Agr. 19(1):7.

Aykroyd, W.R., Krishnan, B.G., Passmore, R. and Sunderajan, A.R.
1940 The rice problem in India. Indian Med. Res. Memoirs, Calcutta 32:84.

Bandopadhyay, B. and Ghose, T.K.
1965 Studies on hydration of Indian paddy: I-A rate equation for the soaking operation. Indian J. Technol. 3:360.

Bandyopadhyay, S. and Roy, N.C.
1975 Prediction of time of hydration during parboiling of paddy from activation energy. J. Food Sci. Technol. 12:197.

Bandyopadhyay, S. and Roy, N.C.
1976 Kinetics of absorption of liquid water by paddy grains during parboiling. Indian J. Technol. 14:27.

Bandyopadhyay, S. and Roy, N.C.
1977 Studies on swelling and hydration of paddy by hot soaking. J. Food Sci. Technol. 14:95.

Barber, S.
1972 Milled rice and changes during aging. in 'Rice - Chemistry and Technology'. D.F. Houston (ed.), AACC, St Paul, Minnesota, p.215.

Barron, F.E.
1949 Annual Report of the Institute for Medical Research, Federation of Malaya. p.20.

Bhattacharya, K.R.
1969 Breakage of rice during milling, and effect of parboiling. Cereal Chem. 46:478.

Bhattacharya, K.R.
1978 Rice. in 'Encyclopaedia of Indian Food Industries'. D. Venkateswarulu (ed.), Indian Inst. Tech., Madras (In press).

Bhattacharya, K.R. and Subba Rao, P.V.
1966a Processing conditions and milling yield in parboiling of rice. J. Agr. Food Chem. 14:473.

Bhattacharya, K.R. and Subba Rao, P.V.
1966b Effect of processing conditions on quality of parboiled rice. J. Agr. Food Chem. 14:476.

Bhattacharya, K.R. and Indudhara Swamy, Y.M.
1967 Conditions of drying parboiled paddy for optimum milling quality. Cereal Chem. 44:592.

Bhattacharya, K.R. and Ali, S.Z.
1970 Improvement in commercial sundrying of parboiled paddy for better milling quality. Rice J. 73:3.

Bhattacharya, K.R. and Sowbhagya, C.M.
1971 Water uptake by rice during cooking. Cereal Sci. Today. 16:420.

Bhattacharya, K.R. and Sowbhagya, C.M.
1972a A colorimetric bran pigment method for determining degree of milling of rice. J. Sci. Food Agric. 23:161.

Bhattacharya, K.R. and Sowbhagya, C.M.
1972b An improved alkali reaction test for rice quality. J. Food Technol. 7:323.

Bhattacharya, K.R. and Sowbhagya, C.M.
1978a On viscograms and viscography, with special reference to rice flour. J. Texture Studies. 9:341.

Bhattacharya, K.R. and Sowbhagya, C.M.
1978b The pasting behaviour of rice: A new method of viscography. J. Food Sci. (In press).

Bhattacharya, K.R., Ali, S.Z. and Indudhara Swamy, Y.M.
1971 Commercial drying of parboiled paddy with L.S.U. dryer. J. Food Sci. Technol. 8:57.

Bhattacharya, K.R., Sowbhagya, C.M. and Indudhara Swamy, Y.M.
1972a Some physical properties of paddy and rice and their interrelations. J. Sci. Food Agri. 23:171.

Bhattacharya, K.R., Sowbhagya, C.M. and Indudhara Swamy, Y.M.
1972b Interrelationship between certain physicochemical properties of rice. J. Food Sci. 37:733.

Bhattacharya, K.R., Sowbhagya, C.M. and Indudhara Swamy, Y.M.
1978 Importance of insoluble amylose as a determinant of rice quality. J. Sci. Food Agric. 29:359.

Borasio, L. and Gariboldi, F.
1965 Parboiled rice - Production and use.
Part I - Production. Rice J. 68(5):32.
Part II - Use. Rice J. 68(8):23.

British Guiana Report
1950 Report on the Mahaicony/Abany Development Scheme on the 31st Dec. 1948. Daily Chronicle Ltd.

Brown, R.
1972 Germination. in 'Plant Physiology', F.C. Steward (ed.). Vol. VI C - 'Physiology of Development from Seed to Sexuality'. Academic Press. p.3.

Burns, E.E.
1972 Canned rice foods. in 'Rice - Chemistry and Technology'. D.F. Houston (ed.), AACC St. Paul, Minnesota, p.419.

CFTRI
1965 Rice in India - A Techno-economic Review, Mysore.

Chakravarty, H.B. and Ghose, T.K.
1966 Studies on the hydration of Indian paddy - Part IIIA: Efficiency of elevated temperature on composition of oil in bran. Souvenir of the Seminar on Modern Technology of Rice Milling, Calcutta, 12-14 Aug. 1966. East India Rice Mills Assn. Calcutta, p.21.

Charlton, J.
1923 The prevention of nuisance caused by parboiling of paddy. Agric. Res. Inst. Bull. No.146. Pusa.

Collison, R.
1968 Starch retrogradation.in 'Starch and its Derivatives'. J.A. Radley (ed.), Chapman & Hall, London. p.194.

Craufurd, R.Q.
1960 Breakage of rice during milling. W. Africa Rice Res. Sta. Sci. Rep. No.11.

Craufurd, R.Q.
1962 Moisture changes in raw and parboiled paddy in West Africa and their influence upon milling quality. II - Changes during drying. Empire J. Expt. Agr. 30:321.

Craufurd, R.Q.
1963 Sorption and desorption in raw and parboiled paddy. J. Sci. Food Agr. 14:744.

Craufurd, R.Q.
1964 Moisture changes in raw and parboiled paddy in West Africa and their influence upon milling quality. III - Shade drying of parboiled paddy. Empire J. Expt. Agr. 32:303.

De, H.N. and Rahman, M.
1965 Biochemical and nutritional studies on rice and rice products in East Pakistan. IV - Cytochemical localization of protein and fat in raw and parboiled rice. Sci. Res. (Pakistan) 2:160.

De, H.N., Mian, N.H. and Haque, M.
1966 Biochemical and nutritional investigations on rice products of East Pakistan. V - Differential spectrophotometric investigation on the iodine complex formed with the different varieties of raw and parboiled rice starches. Pakistan J. Sci. Ind. Res. 9:243.

Demont, J.I. and Burns, E.E.
1968 Effect of certain variables in canned rice quality. Food Technol. 22:1168.

Desikachar, H.S.R. and Subrahmanyan, V.
1959 Expansion of new and old rice during cooking. Cereal Chem. 36:385.

Desikachar, H.S.R. and Subrahmanyan, V.
1961 The formation of cracks in rice during wetting and its effect on the cooking characteristics of the cereal. Cereal Chem. 38:356.

Desikachar, H.S.R., Majumder, S.K., Pingale, S.V., Swaminathan, M. and Subrahmanyan, V.
1955 Prevention of off flavours due to fermentation in the commercial production of parboiled rice. Bull. C.F.T.R.I., Mysore. 5(3):50.

Desikachar, H.S.R., Lakshminarayana, S.K. and Subrahmanyan, V.
1957 Improvements in parboiling of paddy. Res. Ind. 2:150.

Desikachar, H.S.R., Bhashyam, M.K. and Parpia, H.A.B.
1967 Relative yield of total and head rice from raw and parboiled paddy. J. Food Sci. Technol. 4:156.

Dimopoulos, J.S. and Muller, H.G.
1972 Effect of processing conditions on protein extraction and composition and on some other physicochemical characteristics of parboiled rice. Cereal Chem. 49:54.

Done, J.
1949 The effects of various treatments of paddy rice on the aneurin and nicotinic acid content of milled grain. Brit. J. Nutrit. 3:335.

Durrani, O.A.K.
1950 Treating rice. U.S. Patent 2,498,573. Feb. 21. (Chem. Abs. 44:4603f, 1950)

Durrani, O.A.K.
1956 Processing rice paddy. U.S. Patent 2,758,031. Aug. 7. (Chem. Abs. 50:17250g, 1956)

Feillet, P. and Alary, R.
1975 Parboiling of rice. Effect of processing conditions and varietal differences on the quality of finished product. Annales de Technologie Agricole. 24:11. (Food Sci. Technol. Abs. 8:2 M178, 1976)

Ferrel, R.F. and Pence, J.W.
1964 Use of the amylograph to determine extent of cooking in steamed rice. Cereal Chem. 41:1.

Food and Agriculture Organisation.
1954 Rice and Rice diets - A nutritional survey (Revised). F.A.O., Rome.

Food and Agriculture Organisation.
1977 Production Yearbook 1976, Rome 29:94.

Fukui, T. and Nikuni, Z.
1956 Degradation of starch in the endosperm of rice seeds during germination. J. Biochem. Japan. 43:33.

Gariboldi, F.
1972 Parboiled rice. in 'Rice - Chemistry and Technology'. D.F. Houston (ed.), AACC, St. Paul, Minnesota, p.358.

Gariboldi, F.
1974 Rice parboiling. FAO Agricultural Development paper No. 97, F.A.O., Rome.

Ghose, R.L.M., Ghatge, M.B. and Subrahmanyan, V.
1960 Rice in India. Revised ed., I.C.A.R., New Delhi.

Grist, D.H.
1959 'Rice'. Third Edition, Longmans Green & Co.

Halick, J.V. and Keneaster, K.K.
1956 The use of starch-iodine blue test as a quality indicator of white milled rice. Cereal Chem. 33:315.

Halick, J.V. and Kelly, V.J.
1959 Gelatinization and pasting characteristics of rice varieties as related to cooking behaviour. Cereal Chem. 36:91.

Halim, A. and Bhattacharya, K.R.
1978 Effect of degree and pressure of milling on the stickiness of milled parboiled rice. J. Food Qual. 1:349.

Hall, V.L. and Johnson, J.R.
1966 A revised starch-iodine blue test for raw milled rice. Cereal Chem. 43:297.

Hinton, J.C.C.
1948 Parboiling treatment of rice. Nature 162:913.

Hogan, J.T.
1967 Processed rice products. Rice J. 70:25.

Houston, D.F. and Kohler, G.O.
1970 'Nutritional properties of rice'. National Academy of Science, Washington, D.C.

Houston, D.F., Hunter, I.R., McComb, Elizabeth, A. and Kester, E.B.
1954 Deteriorative changes in the oil fraction of stored parboiled rice. J. Agr. Food Chem. 2:1185.

Houston, D.F., Hunter, I.R. and Kester, E.B.
1956 Storage changes in parboiled rice. J. Agr. Food Chem. 4:964.

Indudhara Swamy, Y.M., Ali, S.Z. and Bhattacharya, K.R.
1971 Hydration of raw and parboiled rice and paddy at room temperature. J. Food Sci. Technol. 8:20.

Indudhara Swamy, Y.M., Sowbhagya, C.M. and Bhattacharya, K.R.
1978 Changes in the physicochemical properties of rice with aging. J. Sci. Food Agric. 29:627.

International Rice Commission.
1949 Report of the First Session, F.A.O., Bangkok.

Jayanarayanan, E.K.
1964 Effect of operating conditions on the browning of parboiled rice. Nahrung 8:129.

Johnson, R.M.
1965 Light-reflectance meter measures degree of milling and parboiling of parboiled rice. Cereal Chem. 42:167.

Jones, J.W. and Taylor, J.F.
1935 Effect of parboiling rough rice on milling quality. USDA Circ. No.340, Washington D.C.

Jones, W.W. and Brewer, G.W.
1950 Treatment of rice paddies for milling. U.S. Patent 2,515,409. July 18. (Chem. Abs. 44:9084a, 1950)

Jones, J.W., Zeleny, L. and Taylor, J.F.
1946 Effect of parboiling and related treatments on the milling, nutritional and cooking qualities of rice. USDA Circ. No.752, Washington D.C.

Juliano, B.O., Cagampang, Gloria, B., Cruz, L.J. and Santiago, R.G.
1964 Some physicochemical properties of rice in Southeast Asia. Cereal Chem. 41:275.

Juliano, B.O., Cartano, A.V. and Vidal, A.J.
1968 Note on a limitation of starch-iodine blue test for milled rice amylose. Cereal Chem. 45:63.

Kester, E.B. and Matz, S.A.
1970 Rice processing. in 'Cereal Technology', S.A.Matz (ed.), AVI Publishing Co., Westport, Conn., p.338.

Khuda, M.Q., De, H.N. and Rahman, M.
1962 Biochemical and nutritional investigations on rice and rice products of East Pakistan. I - Differential study of the changes in the size of the paddy and rice and photomicrographic investigations on the alteration of starch constituents due to parboiling. Pakistan J. Sci. Ind. Res. 5:238.

Kik, M.C.
1945a Effect of milling, processing, washing, cooking and storing on thiamine, riboflavin and niacin in rice. Ark. Agr. Expt. Station Bull. No.458.

Kik, M.C.
1945b Parboiling rice. Rice J. 48(12):6.

Kik, M.C.
1946 Rice conversion. Rice J. 49(1):4.

Kik, M.C.
1955 Influence of processing on nutritive value of milled rice. J. Agr. Food Chem. 3:600.

Kik, M.C. and Williams, R.R.
1945 The nutritional improvement of white rice. Bulletin 112. National Research Council (USA), Washington, D.C.

Kireev, V.M. and Mel'nikov, E.M.
1974 Quality of rice kernels as a function of hydrothermal processing conditions of the grains. Isvestiya Vysshikh Uchebnykh Zavedenii, Pishchevaya Tekhnologiya. 1974(1):58. (Food Sci. Technol. Abs. 8:8 M951, 1976)

Kisan Krishi Yantra Udyog, Kanpur.
1972 Automatic parboiling and drying of paddy, prospects and promises - a performance study. Government of India. (c.f. Ali & Ojha 1976a)

Kumar David, J.S., Rao, D.M., Thirumala Rao, S.D. and Murti, K.S.
1964 Studies on Indian rice bran and rice bran oil - II. Indian Oilseeds J. 8:49.

Kuppuswamy, M.
1972 A mathematical model for a continuous system of paddy parboiling. J. Agric. Eng. 9(3):53. (C.f. Ali & Ojha 1976a)

Kurien, P.P., Radhakrishnamurthy, R., Desikachar, H.S.R. and Subrahmanyan, V.
1964 Effect of parboiling on swelling quality of rice. Cereal Chem. 41:16.

Kuz'mina, O.V. and Torzhinskaya, L.R.
1973 The effect of hydrothermal treatment of rice and buckwheat on properties of starch. Izvestiya Vysshikh Uchebnykh Zavedenii, Pishchevaya Tekhnologia. 1973(2):45. (Food Sci. Technol. Abs. 6:2 M252, 1974)

Landon, R.W., Talmey, P. and Gutzeit, G.
1951 Treating rice prior to milling. U.S. Patent 2,546,456 Mar. 27. (Chem. Abs. 45:5337b, 1951)

Little, R.R., Hilder, G.B. and Dawson, E.H.
1958 Differential effect of dilute alkali on 25 varieties of milled white rice. Cereal Chem. 35:111.

Maga, J.A.
1975 Bread staling. CRC Critical Rev. Food Technol. 5:443.

Mahadevappa, M. and Desikachar, H.S.R.
1968a Some observations on histology of raw and parboiled rice. J. Food Sci. Technol. 5:72.

Mahadevappa, M. and Desikachar, H.S.R.
1968b Expansion and swelling of raw and parboiled rice during cooking. J. Food Sci. Technol. 5:57.

Massey-Ferguson Limited.
1967 'Mechanisation and the world's rice'. Massey-Ferguson (Export) Limited. Basil Blackwell, Oxford.

Matz, S.A. and Beachell, H.M.
1969 Rice. in 'Cereal Science', S.A. Matz (ed.), AVI Publishing Co., Westport, Conn., p.150.

Mazumder, A.C., Bose, A.N., Ganguli, N.C. and Guha, B.C.
1960a Pilot plant studies on parboiling of rice. I - Soaking and gelatinization. J. Biochem. Microbiol. Technol. and Engg. 2:431.

Mazumder, A.C., Bose, A.N., Ganguli, N.C. and Guha, B.C.
1960b Pilot plant studies on parboiling of rice. II - Dehydration. J. Biochem. Microbiol. Technol. Engg. 2:439.

Mazumder, A.C., Bose, A.N., Ganguli, N.C. and Guha, B.C.
1960c Pilot plant studies on parboiling of rice. III - Effect of hot soaking and mechanical drying on the nutritive value of parboiled rice. J. Biochem. Microbiol. Technol. Engg. 2:447.

Mazurs, E.G., Schoch, T.J. and Kite, F.E.
1957 Graphical analysis of the Brabender viscosity curves of various starches. Cereal Chem. 34:141.

McLeod, A.M., Duffus, J.H. and Johnston, C.S.
1964 Development of hydrolytic enzymes in germinating grain. J. Inst. Brew. 70:521.

McNair, D.J.
1966 Growth and development during germination of pea seeds. Ph.D. Thesis, University of Edinburgh. (c.f. Brown. 1972)

Mecham, D.K., Kester, E.D. and Pence, J.W.
1961 Parboiling characteristics of California medium-grain rice. Food Technol. 15:475.

Misra, S.B. and Mohan Rao, V.K.
1960 Quantitative estimation of carbohydrates by paper partition chromatography. J. Sci. Ind. Res. 19:173.

Mitsuda, H., Yasumoto, K., Murakami, K., Kusano, T. and Kishida, H.
1967 Studies on the proteinaceous subcellular particles in rice endosperm: Electron-microscopy and isolation. Agr. Biol. Chem. 31:293.

Murata, T., Akazawa, T. and Fukuchi, S.
1968 Enzymic mechanism of starch breakdown in germinating rice seeds. I - An analytical study. Plant Physiol. 43:1899.

Narayanaswami, C.K.
1956 'The Rice We Eat', All India Khadi and Village Industries Board, Bombay.

Nelson, N.
1944 A photometric adaptation of the Somogyi method for the determination of glucose. J. Biol. Chem. 153:375.

Nicholls, L.
1947 Thiamine of milled raw and parboiled rice. Nature 160:298.

Padua, A.B. and Juliano, B.O.
1974 Effect of parboiling on thiamin, protein and fat of rice. J. Sci. Food Agr. 25:697.

Palmiano, E.P. and Juliano, B.O.
1972 Biochemical changes in the rice grain during germination. Plant Physiol. 49:751.

Palmiano, E.P. and Juliano, B.O.
1973 Changes in the activity of some hydrolases, peroxidase and catalase in the rice seed during germination. Plant Physiol. 52:274.

Powell, E.L.
1967 Production and use of pregelatinized starch. in 'Starch: Chemistry and Technology', Vol.II., R.L. Whistler and E.F. Paschall (eds), Academic Press, p.523.

Pratt, Jr., D.B.
1971 Criteria of flour quality. in 'Wheat - Chemistry and Technology'. 2nd Edn, Y. Pomeranz (ed.), AACC, St. Paul, Minnesota, p.201.

Priestley, R.J.
1976a Studies on parboiled rice. Part 1 - Comparison of the characteristics of raw and parboiled rice. Food Chem. 1:5.

Priestley, R.J.
1976b Studies on parboiled rice. Part 2 - Quantitative study of the effects of steaming on various properties of parboiled rice. Food Chem. 1:139.

Priestley, R.J.
1977 Studies on parboiled rice. Part 3 - Characteristics of parboiled rice on recooking. Food Chem. 2:43.

Raghavendra Rao, S.N. and Juliano, B.O.
1970 Effect of parboiling on some physicochemical properties of rice. J. Agr. Food Chem. 18:289.

Raghavendra Rao, S.N., Ananthachar, T.K. and Desikachar, H.S.R.
1965 Oil content of bran from rice milled to different degrees of milling. J. Food Sci. Technol. 2:115.

Raghavendra Rao, S.N., Narayana, M.N. and Desikachar, H.S.R.
1967 Studies on some comparative milling properties of raw and parboiled rice. J. Food Sci. Technol. 4:150.

Rama Rao, V.V. and Bonde, R.S.
1977 Drying characteristics of parboiled paddy. R.P.E.C. Reporter. 3(1):13.

Roberts, R.L.
1972 Quick cooking rice. in 'Rice - Chemistry and Technology'. D.F. Houston (ed.), AACC, St. Paul, Minnesota, p.381.

Roberts, R.L., Houston, D.F. and Kester, E.B.
1951 Expanded rice product; a new use of parboiled rice. Food Technol. 5:361.

Roberts, R.L., Potter, A.L., Kester, E.B. and Keneaster, K.K.
1954 Effect of processing conditions on the expanded volume, color and soluble starch of parboiled rice. Cereal Chem. 31:121.

del Rosario, A.R., Briones, V.P., Vidal, A.J. and Juliano, B.O.
1968 Composition and endosperm structure of developing and mature rice kernel. Cereal Chem. 45:225.

Rosen, H.
1957 A modified ninhydrin colorimetric analysis for amino acids. Arch. Biochem. Biophys. 67:10.

Sandstedt, R.M. and Abbot, R.C.
1964 A comparison of methods for studying the course of gelatinization. Cereal Sci. Today. 9:13.

Sanjiva Rao, B.
1948a Technology of rice. Current Sci. 17:13.

Sanjiva Rao, B.
1948b Proc. Ind. Sci. Cong. Part II, 259.

Sanjiva Rao, B. and Guha, B.C.
1952 'Report on investigations of the standardization of the parboiling of rice'. Ministry of Food, Government of India.

Sarda, P.S.
1965 Improved method of parboiling in Sarda rice and oil mills. J. Food Sci. Technol. 2:105.

Schoch, T.J.
1965 Starch in bakery products. Baker's Digest. 39(2):48.

Schoch, T.J. and French, D.
1947 Studies on bread staling. I - The role of starch. Cereal Chem. 24:231.

Schroeder, H.W.
1965 Fungus deterioration of rice: Effects of fungus infection on free amino acids and reducing sugars in white and parboiled rice. Cereal Chem. 42:539.

Shivanna, C.S.
1971 Economics of storage and processing of rice. II - Traditional and modern methods of parboiling and drying of paddy. Food Ind. J. 4(5):1.

Simpson, I.A.
1951 Distribution of thiamine and riboflavin in rice grain, and of thiamine in parboiled rice. Cereal Chem. 28:259.

Sircar, S.M. and Datta Ray, P.
1962 Studies on the physiology of rice. XV - Changes in the metabolism of seed during germination and their relation to the application of growth regulators. J. Exp. Bot. 13:61.

Sluyters, J.A.F.M.
1963 Milling studies on parboiled rice in Nigeria. Trop. Agr. (Trinidad), 40:153.

Sluyters, J.A.F.M.
1965 Milling studies on shade dried parboiled rice in Nigeria. Trop. Agr. (Trinidad), 42:163.

Somogyi, M.
1952 Notes on sugar determination. J. Biol. Chem. 195:19.

Sondi, A.B.
1976 Effect of parboiling on the fat content of milled rice and bran. M.Sc.(Food Tech.) Thesis, Univ.of Mysore.

Sowbhagya, C.M. and Bhattacharya, K.R.
1976 Lipid autoxidation in rice. J. Food Sci. 41:1018.

Sreenivasan, A.
1936 Nutritive value of raw and parboiled rice. Proc. Soc. Biol. Chem. (India), 1:41.

Sreenivasan, A.
1938 The loss of embryo on milling raw and parboiled rices. Madras Agr. J. 26:249.

Sreenivasan, A.
1951 The chemistry of rice. J. Sci. Ind. Res. 10A:438.

Stermer, R.A.
1968 An instrument for objective measurement of degree of milling and color of milled rice. Cereal Chem. 45:358.

Subba Rao, P.V. and Bhattacharya, K.R.
1966 Effect of parboiling on thiamine content of rice. J. Agric. Food Chem. 14:479.

Subrahmanyan, V.
1972 Utilization of donatable oxygen as a means of controlling putrefactive changes during the cold soaking of paddy - Successful application in association with traditional and modern mills - Need for intense study of the associated phenomena leading to wider applications. Unpublished report. Paddy Processing Research Centre, Thiruvarur, India.

Subrahmanyan, V., Sreenivasan, A. and Das Gupta, H.P.
1938 Studies on quality in rice. I - Effect of milling on the chemical composition and commercial qualities of raw and parboiled rice. Ind. J. Agr. Sci. 8:459.

Subrahmanyan, V., Desikachar, H.S.R. and Bhatia, D.S.
1955 Commercial methods of parboiling paddy and improvement of the quality of parboiled rice. J. Sci. Ind. Res. 14A:110.

Tanaka, Y., Ito, T. and Akazawa, T.
1970 Enzymic mechanism of starch breakdown in germinating rice seeds. III. α-amylase isozymes. Plant Physiol. 46:650.

Tarasova, V.I., Torzhinskaya, L.R. and Gusev, P.
1971 Effect of hydrothermal treatment of rice on its biochemical properties. Izvestiya Vysshikh Uchebnykh Zavedenii, Pishchevaya Tekhnologiya, 1971(2):72. (Food Sci. Technol. Abs. 4:4 M394, 1972)

Tata, S.N.
1962 Parboiled rice. Rice News Teller. 10(2/3):50.

Tata, S.N.
1964 Parboiled paddy has many favourable points. Indian Farming 14(2):4.

Vasan, B.S., Iengar, N.G.C., Subramanyam, T.V., Chandrasekaran, R. and Subrahmanyan, V.
1971 Effect of processing on the movement of oil in the rice kernel and its relation to the oil content of paddy and the yield of oil from rice bran. Inter-regional Seminar on the Industrial Processing of Rice, Madras.

Vasan, B.S., Iengar, N.G.C., Nagasubramanian, M., Bhasker, R., Shivanna, C.S., Mohandoss, R. and Subrahmanyan, V.
1973 Studies on the action of cations on paddy with particular reference to the role of sodium ion and its application in the preservation, parboiling and drying of paddy. Proc. Indian Natl. Sci. Acad. 39B:32.

Williams, K.T. and Bevenue, A.
1953 A note on the sugars in rice. Cereal Chem. 30:267.

Williams, P.C. and Fegol, K.S.W.
1969 Colorimetric determination of damaged starch in flour. Cereal Chem. 46:56.

Winton, A.L. and Winton, K.B.
1932 'Structure and Composition of Foods', Vol.I, John Wiley & Sons, New York, p.130.

Zeleny, L.
1971 Criteria of wheat quality. in 'Wheat - Chemistry and Technology', 2nd Edn, Y. Pomeranz (ed.), AACC, St. Paul, Minnesota, p.19.

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